PROTEIN MALNUTRITION, PREVENTIVE MEASURES, ALTERNATIVE PROTEIN SOURCES FROM DIETARY BY-PRODUCTS, AND INSECT-DERIVED PROTEIN

Abstract

This chapter introduces preventive measures for protein malnutrition as a significant public health concern and alternative protein sources. It starts by presenting an overview of the consequences of chronic protein malnutrition in children and adults; prevention strategies, including improved access to protein-rich foods; promoting education on balanced diets; early detection and treatment as well as agricultural development programs that enhance the production and availability of protein-rich foods and promote sustainable practices. It then explains the valorization of the food agro-industry by-products as an alternative source of protein and their extraction methods. By the end of the chapter, a discussion on the applicability of cricket flour as aprotein fortifier in the Food Industry and its general and microbiological safety is presented, focusing on several studies described in the scientific literature.

Keyword: Protein-rich food;food waste; extraction; cricket flour; gluten-free food.

Authors

Aichurok Mazhitova
Department of Food Engineering,
Kyrgyz-Turkish Manas University,
Bishkek, Kyrgyz Republic.
aichurok.mazhitova@manas.edu.kg

Azhar Makambai kyzy
Department of Food Engineering,
Kyrgyz-Turkish Manas University,
Bishkek, Kyrgyz Republic.

Bermet Sultanova
Department of Food Engineering,
Kyrgyz-Turkish Manas University,
Bishkek, Kyrgyz Republic.

Akylai Chynalieva
Department of Food Engineering,
Kyrgyz-Turkish Manas University,
Bishkek, Kyrgyz Republic.

I. INTRODUCTION

Insufficient protein intake can lead to protein malnutrition (PM) when the body's needs are not met. This can have severe consequences for health, including stunted growth and development, weakened immune system, and impaired cognitive function. PM is a major concern globally, especially in low-income countries and among vulnerable groups like children and pregnant women [1]. The World Health Organization (WHO) reports that an average adult needs 0.83 grams of protein per kilogram of body weight per day to stay healthy, while the minimum requirement is 0.66 grams [2]. However, protein needs can vary based on age, sex, physical activity levels, and other factors. While there is no one-size-fits-all recommendation for protein intake, it's generally suggested that protein should make up 10-35% of daily energy intake [3].

Despite its importance, protein can also be a costly and complex dietary element thatraises economic, environmental, and political concerns [4]. PM remains a major public health issue, especially in low- and middle-income countries. According to WHO, an estimated 462 million people worldwide suffer from malnutrition, including PM [5]. The Global Hunger Index (GHI) also highlights that as of 2022, 9 countries still have "alarming" levels of hunger,with sub-Saharan Africa being the most affected region [6]. The highest prevalence of PM is found in South Asia and Sub-Saharan Africa, where around 11-13% of the population is affected [7]. Children are particularly vulnerable to malnutrition, including PM; in 2020,

149.2 million children under 5 years of age were too short for their age (stunted), and 45.4 million were too thin for their height (wasting) [8].

PM can negatively impact health, including stunting, wasting, impaired immunity, and cognitive impairment. When it is chronic, it can lead to hindered growth and development, particularly in children. This can also cause stunted height, which may be irreversible [9-12]. Maternal malnutrition during pregnancy can also have long-term consequences for both the mother and child [13]. Acute PM can result in rapid weight loss and muscle wasting [14-16]. A study conducted in Pakistan's public hospital found that girlshad a higher prevalence of undernutrition than boys, and children under five failed to meet their necessary nutritional needs [17].

Furthermore, childhood PM can lead to long-lasting effects on cognitive development and academic performance [18, 19]. It can also weaken the immune system, making individuals more vulnerable to infections and other diseases [20]. One primary mechanism is the inadequate provision of vital nutrients necessary for immune system cells to perform their functions effectively. Thus, protein energy malnutrition deprives immune cells of essential nutrients, hindering their ability to carry out their intended roles [21]. Individuals with certain medical conditions, such as inflammatory bowel disease, celiac disease, and food allergies, may also have impaired protein absorption from food [22, 23].

Understanding the causes and consequences of PM is crucial for public health effortsto reduce its prevalence [24]. PM can result from various causes and risk factors, including insufficient intake of protein-rich foods like meat, fish, eggs, and dairy products [25]. Failure to meet the increased protein requirements of specific populations, such as athletes and pregnant women, can also lead to PM [26]. Additionally, limited access to nutritious foods due to poverty and food insecurity can increase the risk of PM. Finally, natural disasters, armed conflicts, and other environmental factors can disrupt food supplies, further raising therisk of PM [27]. The study aims to assess PM comprehensively, explore various methods to mitigate its occurrence and investigate alternative protein sources from agro-industrial by- products and edible insects.

II. PROTEIN MALNUTRITION AND PREVENTING MEASURES

1. **Protein-Energy Malnutrition:** Before the 1980s, efforts to combat malnutrition in developing countries mainly focused on addressing protein and energy deficiencies [28]. Protein-energy malnutrition (PEM) is a group of growth disorders in children caused byinadequate protein and energy intake. Unlike PM alone, PEM can lead to more severe outcomes [29]. Malnutrition is prevalent in low and middle-income countries [30]. Primary PEM is most common in developing countries where the food supply is insufficient due to socioeconomic, political, and sometimes environmental factors such as natural disasters [20]. According to WHO statistics from 2020, the largest number of PEM-related deaths (5,000) in Mexico were among people aged 75 and above, with 1,000 deaths occurring in people aged 55-74, and approximately 400 deaths were recorded in individuals aged 35-54. It is evident that mortality rates tend to increase with age [31].

   PEM refers to three different clinical syndromes. The first is stunting, which is caused by chronic malnutrition during pregnancy or early childhood and affects both macro and micronutrient intake. The second syndrome is severe acute malnutrition (SAM), which includes kwashiorkor and marasmus and primarily affects micronutrient intake. The third syndrome is wasting or cachexia, which occurs as a secondary syndromedue to acute or chronic underlying disorders [32].

   The two main severe forms of PEM are marasmus and kwashiorkor, although a combination of both may also occur. They are distinguished based on clinical manifestations, with the primary difference between the two being the presence of edema in kwashiorkor [20]. It should be noted that marasmus, kwashiorkor, and intermediate states of marasmus kwashiorkor are also considered as severe acute malnutrition [33].

   - **Marasmus:** Marasmus is a condition that is characterized by extreme thinness, depletion of fat stores, muscle wasting, and absence of edema [33]. The term 'marasmus' originates from the Greek word that means withering or wasting. This type of malnutrition is caused by a lack of protein and calories in the diet [20, 32]. It is more common in children under 5 years old due to increased caloric requirements and susceptibility to infections. Severely affected children may have a monkey-like or aged appearance due to the loss of buccal fat pads. The child appears emaciated, weak, and lethargic, with xerotic and wrinkled skin. Muscle wasting usually starts in the axilla and groin due to severe deprivation of calories and nutrients [20].

- **Kwashiorkor:** Kwashiorkor comes from the Ghanaian language and means "the sickness of the weaning" or "the disease of the displaced child" when they stop breastfeeding. It is a form of malnutrition that happens when someone doesn't get enough protein in their diet but still consumes enough calories [33]. This condition often affects older infants and young children with a reasonable calorie intake but insufficient protein. Children with kwashiorkor often eat a diet low in protein but high in carbohydrates, so they are sometimes called "sugar babies." The symptoms of kwashiorkor include swollen body parts, skin problems, a bloated stomach, and an enlarged liver [20]. People with kwashiorkor have more serious protein depletion in their liver, which can lead to low levels of albumin, a bloated stomach, and a fatty liver [33]. Kwashiorkor has a higher mortality rate than Marasmus, another type of malnutrition. People with both conditions have a very high risk of death [34]. People with kwashiorkor may also have mild hair and skin changes and an enlarged fatty liver that can be felt during a physical examination [20].

- **Importance of Animal-Source Protein:** Animal-source foods have some disadvantages, including complex scientific, economic, environmental, and politicalissues and high energy demands. However, they are highly regarded as a superior source of protein due to their exceptional amino acid profile. Incorporating more fatty fish and dairy products into a macrobiotic diet can promote accelerated growth in young children experiencing stunting [36, 37]. Animal products are rich in micronutrients, such as iron, zinc, vitamin A, vitamin B12, riboflavin, and calcium, making them an effective source for meeting nutritional needs. However, the consumption of milk along with meat reduces the absorption of iron and zinc [38]. Meat is rich in iron and zinc, particularly in the form of heme protein, which enhances the absorption of these minerals from other sources. Nevertheless, the high fat and saturated fatty acid levels found in certain animal-derived foods like meat have raised concerns regarding their potential impact on the risk of cardiovascular disease, metabolic syndrome, and other chronic illnesses [39].

2. **Preventing Measures for Protein Malnutrition:** Prevention of PM can be achieved through various methods, such as education on having a balanced diet and improving access to protein-rich foods. Agricultural and economic development can also aid in increasing the availability of such foods. Early detection and treatment of PM are crucial in preventing long-term health consequences like impaired growth and cognitive development [24]. According to the World Health Organization (WHO), the recommended protein consumption for an adult male weighing 90 kg is 75g per day. However, from 1990 to 2007, the world's protein consumption was 76-85 g/person/day. In the developing world, this value falls to 80 g per person per day, while in Africa, it's even lower at 62 g per person per day [40]. Individuals experiencing mild malnutrition consume 51% to 75% of the recommended energy and protein levels necessary for their well-being. For those with moderate malnutrition, the intake is 26% to 50% of the required energy and protein levels. In the case of severe malnutrition, individuals consume less than 25% of the necessary energy intake [41].

- **Balanced Diet:** In developing countries, dietary protein sources are mainly limited to cereals like rice, wheat, and maize, with animal-based sources playing a lesser role. Although there are health and environmental concerns related to animal products, they play a crucial role in the global food chain [42]. A balanced diet is essential in preventing protein deficiency, influenced by various factors beyond limited access to specific foods, including animal-based products [4]. It is crucial to emphasize the importance of the food source's quality, and promote a well-balanced diet that includes sufficient protein from both animal and plant sources. Dietary protein quality is often assessed using PDCAAS, which determines its utilizable protein content based on amino acid composition. Certain amino acids like methionine, lysine, tryptophan, and threonine are considered essential amino acids and often the limiting factors in the nutritive value of proteins in the human diet [43]. To optimize the protein quality of a plant-based meal, carefully selecting a combination of plant-based protein foods that compensate for each other's amino acid deficiencies is essential. However, this task can be challenging, given the limited food choices available [4].

  In developing countries, combining vegetable protein and cereals in meals is expected to increase protein content. However, both types of food contain phytic acid, which can hinder the absorption of essential minerals such as iron, zinc, calcium, and manganese [44]. Complete enzymatic degradation is recommended to break down phytic acid, but this may not always be possible. Animal-based protein sources do not contain anti-nutrient factors, unlike plant-based sources. Studies have shown that adding even a small amount of animal products to meals can significantly improve the absorption of essential minerals such as iron and zinc [4]. Therefore, it is recommended to include lean meats, poultry, fish, dairy products, eggs, legumes, nuts, and seeds in the diet.

- **Agricultural Development:** There are various ways to address PM, such as supporting agricultural development programs that enhance the production and accessibility of protein-rich foods, promoting sustainable agricultural practices, and diversifying crops to offer alternative protein sources [45]. Some experts recommend improving dietary diversity and nutrition through agriculture. They suggest that agricultural development programs prioritize food and nutrition security. Nutrition security pertains to the quality aspect of food production, consumption, and utilization, ensuring that people can access a variety of high-quality foods that meet their macro and micronutrient requirements. To bridge the nutrition gap and enhance nutrition security, several strategies can be implemented in agriculture, including increasing small-scale production of nutrient-rich fruits, vegetables, legumes, and animal-source foods, boosting commercial production of nutrient-rich foods to make them more available and accessible to consumers, minimizing post-harvest losses, selecting and breeding plants, and using extension-based education and social marketing tactics.

Other authors stress the significance of incorporating livestock and aquaculture into agricultural production systems as a holistic approach to food production and security. They highlight that animal-derived foods from these systems can substantially address nutrient deficiencies in adults and children [46]. They argue for the need to promote diversified farming systems, like integrated crop and livestock systems and aquaculture, to achieve this goal. For instance, they suggest the Asian or Latin American aquaculture/livestock model, where a pig farm is built over a pond, and undigested grains from pig dung and grass from the banks of the pond serve as feed resources. This system enables farmers to produce pork, fish, and duck products from a small plot of land, using nitrogen-rich pond runoff as a fertilizer for crops.

Currently, the agriculture and food systems need more production diversity, leading to unbalanced diets and consequent malnutrition [47]. The study conducted by Li et al. (2020) focused on hunger and malnutrition in Asia and the Pacific [48]. They highlighted the importance of having a diverse diet and cultivating a variety of crops to combat malnutrition in the region. The Asia Pacific region mainly relies on a few staple crops, with rice being the most commonly grown. However, this lack of dietary diversity often leads to inadequate nutrition, falling short of the recommended intake levels. The authors of another study suggest that neglected and underutilized species (NUS) can potentially improve both dietary quality and agricultural productivity [49]. One example of a highly nutritious NUS is quinoa, which gained popularity in 2014 when the United Nations General Assembly endorsed it as the International Year of Quinoa. Quinoa has twice as much protein, five times more dietary fiber, four times more iron, and 23 times more folate than rice. Another NUS that can provide adequate dietary amounts of micronutrients like iron, zinc, and selenium is lentils.

- **Breastfeeding:** Breastfeeding is a crucial way to prevent Kwashiorkor in children, as weaning from breastfeeding is the main cause of the disease. It provides children with the nutrients for a balanced diet and helps prevent protein deficiency. Scientific evidence supports promoting infant feeding as an intervention that enhances growth and development, leading to optimal outcomes [50]. It is recommended that breastfeeding continue until the child is two years old, which has many benefits for both mother and child. Breastfeeding reduces the risk of cancer for mothers, including breast and ovarian cancers [51]. Breast milk is considered the ideal source of infant nutrition and contains all necessary nutrients in the proper proportions. It also provides non-nutritive components, such as antibodies and immune factors that help protect against infections. Breast milk contains long-chain polyunsaturated fatty acids like docosahexaenoic acid, essential for brain development and may contribute to improved cognitive abilities later in life [52].

Women of reproductive age, as well as the developing fetus and young children, are vulnerable to malnutrition and require essential nutrients for fetal growth and milk production. Vitamin B12 is important during this stage, and breast milk is a critical source of this nutrient [53]. Once a child has been breastfed for six months, it is essential to introduce various complementary foods to receive all the necessary nutrients. Seven food categories are suitable for children aged between 6 and 24 months. These include cereals, tubers, and root vegetables; legumes and nuts; meat products; fruits and vegetables high in vitamin A; dairy products; eggs; and other vegetables and fruits. It is recommended that children consume at least 4 of these seven food groups, focusing on protein, indicating sufficient dietary diversity [54]. The reason behind the four food groups being the cut-off point is to ensure that a child's diet includes either an animal source food or a high-protein source such as legumes or nuts. Recommended nutrient intakes for infants and young children are established as adequate due to insufficient evidence to determine a recommended allowance for this age group. Similarly, there is no evidence for recommended feeding practices throughout the preschool-age period (2 to 5 years of age) [55].

- **Nutritional Education:** Malnutrition is a global problem that affects people of all ages and cultures. It can cause a range of physiological issues, such as weakened immune function, reduced strength, and impaired renal and cardiac function [56]. In Ghana, data from the 2003 Demographic and Health Survey showed that malnutritionis linked to poverty and maternal education [57]. These findings highlight theimportance of addressing non-health-related goals such as eradicating extreme poverty/hunger, achieving universal primary education, promoting gender equality and women's empowerment, and ensuring environmental sustainability to prevent malnutrition [58]. Researchers studying kwashiorkor and marasmus have found that milk is an ideal basis for therapy and prevention, but properly formulated vegetable protein mixtures are also effective for treatment and prevention in many parts of the world. They also note the correlation between diarrheal disease and severe PM and suggest that improving environmental sanitation can help reduce the prevalence of kwashiorkor. Finally, this study emphasizes the need for nutrition education to improve feeding practices for weaned infants and young children as a significant factor in preventing kwashiorkor [59].

  Many older adults lack nutritional knowledge, including understanding their protein requirements and how protein/diet affects their health [60]. Only one study inthe past 20 years has focused explicitly on protein intake as a topic for community- based education, and it was successful in increasing protein intake for the interventiongroup [61]. To further promote healthy balanced diets, community-based cooking workshops could be held by dietitians. These workshops would incorporate nutritional education alongside the cooking sessions while providing recipes for participants to practice and learn to replicate at home. Although these workshops may not prevent or address PEM, they could help address protein needs by promoting healthy dietary habits and being organized by dietitians [62].

- **Food Fortification:** While protein-energy malnutrition remains a critical concern, recent studies have shown an increased understanding of the impact of micronutrient deficiencies on human health and well-being [28]. Protein deficiency is often accompanied by micronutrient deficiencies, and malnutrition caused by inadequate intake of essential vitamins, minerals, and trace elements can coexist with protein- energy malnutrition. Even those who are generally well-nourished may experience specific deficiencies in certain vitamins or minerals [21]. Micronutrient deficiencies are prevalent in both industrialized countries and developing regions of the world, and studies show a growing prevalence of malnutrition among hospitalized individuals indeveloped countries [63].

Fortification is the intentional process of enhancing the levels of vital micronutrients, such as vitamins and minerals (including trace elements), in specific food items. This aims to improve the nutritional value of the food supply, promoting public health benefits while minimizing potential health risks [28]. The most common deficiencies are essential micronutrients such as iron, vitamin A, and iodine, which can have adverse effects on human health. For example, iodized salt was one of the first fortified foods introduced in Switzerland [64] and the United States of America[65], and it has since expanded worldwide and is now commonly used in mostcountries.

III. ALTERNATIVE PROTEIN SOURCES FROM AGRO-INDUSTRIAL BY-PRODUCTS

The food agro-industry produces various by-products such as spoiled raw materials, pomace, leaves, seeds, shells, bran, oilcake, and molasses. These by-products are discarded and can cause environmental issues [66]. According to the Food and Agriculture Organization of the United Nations (FAO), the agro-food industry produces around 190 million tons of by-products globally annually [67]. By-products made at all food production and consumption stages can affect food security and should not be ignored [68]. Many researchers have studied the bioactive compounds found in agro-industrial by-products. Food by-products have great potential for processing as they contain proteins, carbohydrates, lipids, phenolic compounds, dietary fiber, and pigments. These compounds can be used to create new food products or ingredients for human consumption, contributing to their complex valorization and re-inclusion in the food supply chain in the circular bioeconomy. This, in turn, can generate revenue streams, business opportunities, and jobs [69-71].

Scientists across various fields have shown an interest in extracting protein from plant by-products, as it offers a low-cost and environmentally friendly source of nutrients [72]. With the world's population increasing, there is a growing need for proteins that are easily accessible and beneficial to our health, especially for children and the elderly [73, 74]. It is estimated that around 6.8 million tons of protein will be needed for human consumption by 2025 [75]. Proteins, which can be derived from both plant and animal sources, are macromolecules that play a crucial role in providing nutrients to our bodies [76].

1. **Sources of Agro-Industrial Waste:** The importance of food security and the challenge of feeding a growing global population has led to the search for sustainable and environmentally-friendly sources of highly nutritious products, including alternative protein sources [73]. As the food industry continues to industrialize, there is potential toutilize residues from fruit and vegetable processing and animal by-products to create valuable protein products [72, 78]. Due to the diverse functional properties of proteins, their applications in various industries are expanding [79]. Reports have been published on protein extraction from plant and

animal by-products (Table 1).

- **Meat and Poultry Processing Industry by-Products:** The demand for meat production is increasing, and in order to meet this demand, there needs to be a more efficient use of resources. Currently, meat by-products contain high-quality proteins and other nutrients that need to be fully utilized. It is important to reconsider their value [104]. The protein-containing wastes from processing farm animals and poultry can be categorized into different types based on their composition and processing techniques. These types include meat-containing, keratin-containing, collagen- containing, and blood [105]. Collagen, which makes up a significant percentage of mammalian body proteins (25-35%), is the foundation of connective tissue and has a unique amino acid composition rich in glycine, proline, and oxyproline (33% and 22%, respectively) [106].

  The poultry industry produces vast waste feathers each year, estimated at 12 million tons worldwide. Thanks to technological advancements, these feathers contain about 90% protein-keratin and can be repurposed into high-quality regenerated filaments [81]. Recent studies by Nuutinen et al. (2019), Mu et al. (2020), and Mi et al. (2020) have confirmed that poultry feathers can be utilized to create keratin filaments [80, 81, 83]. Additionally, Wubshet et al. (2018) and Lindberg et al. (2021) have conducted research on the use of poultry by-products to produce myofibrillar and collagen proteins [84, 85]. Due to their unique properties, these proteins can be used in biomedicine and biotechnology to create nanoparticles, scaffolds for cell engineering, bioplastics, bioremediation agents, and oligopeptides and amino acids [107]. Gelatin can also be obtained from bovine bone collagen, as demonstrated by Cao et al. (2020) [82]. Collagen hydrolysates are commonly used in the food industry to improve the organoleptic and physicochemical properties of meat products, beverages, and soups [108, 109]. Collagen and keratin, comprising a significant portion of animal-origin protein waste, have almost limitless potential for biotechnological applications [109].

Table 1: Protein products obtained from various agro-industrial by-products and methods of extraction

Protein types	Agro-industrial waste	Extraction method	Reference
Meat and poultry processing industry by-products			
Keratin	Poultry feathers	In a deep eutectic aqueous solvent	[80]
Keratin fibers	Chicken feathers	Step-by-step oxidation and extraction technology	[81]

Gelatin	Bovine bone collagen	Various acids (hydrochloric, acetic, and citric) with and without pepsin	[82]
Keratin threads	White duck feathers	Using dithiol reducing agent	[83]
Squirrels	Poultry by-products	Enzymatic protein hydrolysis	[84]
Myofibrillar and collagen proteins	Poultry offal	Enzymatic hydrolysis of protein	[85]
Fish processing industry by-products			
Collagen proteins	Fish skins		[86]
Collagen	Sturgeon fish skin (Huso huso)	Acid and enzymatic extraction	[87]
Protein hydrolysate	Waste from squid processing	Treatment with the enzyme preparation	[88]
		"Protepsin" and citric acid solution	
Collagen	Bester sturgeon Huso huso× Acipenser ruthenus	Enzymatic extraction	[89]
Dairy production by-products			
Squirrels	Bovine and ovine dairy by-products	Precipitation with ammonium sulfate	[90]
Whey proteins	Cheese	Magnetic separation	[91]
Squirrels	Milk whey	Aqueous two-phase extraction	[92]
Casein	Dairy wastewater	Dissolved air flotation	[93]
Fruit and vegetable processing by-products			
Protein isolate	Sugar beet leaves	Soft and food-compatible technologies	[94]
Leaf squirrels	Vegetable by-products: cauliflower, broccoli, cabbage and beets	Alkaline extraction	[95]
Peptide hydrolysates	Cauliflower leaves	Ultrasonic extraction	[96]
Protein	Watermelon seeds	Ultrasonic extraction method	[97]

Protein extracts	Waste and byproducts of mushrooms generated in the supply chain	Water extraction, ultrasound extraction, and enzyme extraction	[98]
Oilseeds processing by-products			
Sunflower protein isolate	Sunflower meal	Ultrasonic extraction	[99]
Protein hydrolyzate	Sesame bran	Enzymatic extraction under the influence of ultrasound	[79]
Cereal and legumes processing by-products			
Protein concentrates	Skimmed rice bran	Ultrasonic extraction	[100]
Soy protein isolate	Soy whey		[101]
Protein concentrate	Durum wheat bran	Alkaline -acid method	[102]
Squirrels	By-products of legumes	Soft extraction techniques	[103]

- **Fish Processing Industry by-Products:** In fish-processing plants, waste products such as heads, scales, skin, fins, vertebral spines, and viscera make up a significant portion of the initial raw material, ranging from 50-70% [105]. The primary product of processing fish waste is protein hydrolysate [79], which offers opportunities for recovering long and short peptides and amino acids [76]. The proteins in the hydrolysate composition have molecular weights ranging from 0.1 to 100 kDa and consist of fragmentarily cleaved proteins containing di-, tri-, and oligopeptides that contain all the essential amino acids [79]. Hydrolysates derived externally are excellent protein sources for individuals with protein digestion issues and have valuable applications in the pharmaceutical and food industries based on their bioactivity and functional properties. Fish protein hydrolysates have functional properties like water retention, emulsifying, gel- and foam-forming abilities, and solubility, making them useful in various food industry technological processes suchas sausage and pate products, sauces and dips, as enriching additives in bakery, confectionery, and dairy products [76].

One form of organic waste is the leftover materials from squid processing, particularly their heads. These heads contain a high concentration of protein substances, making them a promising source for food production. The study conducted by Bredekhin and colleagues in 2019 explored the use of the enzyme preparation "Protepsin" and citric acid solution to produce protein hydrolysate from squid heads [88]. Collagen proteins have also been extensively studied and describedby Antipov et al. (2018), Atef et al. (2020), and Zhang et al. (2020) [86, 87, 89].

- **Dairy Production by-Products:** Whey, a by-product of the dairy industry, is obtained by extracting protein-fat concentrates from milk, such as cheese, cottage cheese, and technical casein. It is an excellent source of highly nutritious proteins with functional properties [110, 111]. Whey proteins comprise around 20% of milk proteins and are globulins and albumin soluble in a wide pH range. They are easy to digest, contain essential amino acids, and are a source of bioactive peptides with antioxidant, antimicrobial, immunomodulatory, and other beneficial properties [112]. Several research papers, including those by Nicolás et al. (2019) and Domínguez- Puerto et al. (2018), have explored the production of whey proteins from dairy by- products [92, 93]. Recent research has shown that protein products can also be obtained from dairy wastewater. For example, Ryder et al. (2018) presented the extraction of casein from dairy wastewater, while Parrón et al. (2018) discussed the extraction of proteins from bovine and egg-milk by-products [90, 93]. Enzymatic hydrolysates of whey proteins are ideal ingredients in breath milk substitutes, sports nutrition products, and specialized preventive and therapeutic products, particularly when they have a certain degree of hydrolysis [113].

- **Fruit and Vegetable Processing by-Products:** Food waste is a significant issue, and fruit and vegetable by-products are a common cause [114]. Recently, a growing interest has been in processing these by-products to extract functional ingredients likeprotein [96]. For instance, Sedlar et al. (2020) found leaf proteins can be produced from vegetable by-products such as cauliflower, broccoli, cabbage, and beets [95]. Similarly, Martin et al. (2018) successfully obtained a protein isolate from sugar beet leaves, as detailed in their research paper [94]. Additionally, watermelon seeds can be a valuable source of proteins, oils, and carbohydrates. Gadalkar et al.'s (2019) study shows that ultrasonic extraction can extract protein from watermelon seeds [97].

- **Oilseed Processing Industry by-Products:** Recently, there has been a growing interest in proteins derived from defatted oilseeds [99]. Sunflower meal, a byproduct of sunflower oil production, is a rich source of protein, containing about 30-50% protein [115]. Unlike protein isolates from other oilseed meals, sunflower protein isolates are free of toxic components and have minimal anti-nutritional components. This makes them a promising alternative source of protein [116]. Research studies byGörgüç et al. (2019), Sá et al. (2020), Özdemir et al. (2022), and Dabbour et al. (2018) have demonstrated the successful extraction of protein isolates and hydrolysates from oilseeds [72, 73, 78, 99].

- **Cereal and Legumes Processing by-Products:** Cereals are a significant food source in our diet, and their processing generates a large number of by-products [117]. Processing cereal crops such as wheat and rice bran can yield protein from lower-cost sources [118]. Recently, protein concentrates have been rapidly developed, with a protein content of 64-73% depending on the type and quality of plant raw materials used and the production technology applied [119]. Ly et al. (2018) and Alzuwaid et al. (2019) have demonstrated the production of protein concentrate using defatted ricebran [100, 102].

  Legumes have been recognized for their nutritional benefits and high protein content for centuries. Soybeans, in particular, are a valuable legume used as a protein source in Asian countries [120]. The consumption of soy products has been growing globally due to their exceptional nutritional value and associated health benefits [121]. Soy protein is similar in nutritional value to meat and milk proteins and is rich in essential amino acids, particularly lysine - the limiting amino acid in plant proteins [122]. A research paper by Chua et al. (2019) shows that soy protein isolates can be produced from soy whey [101]. Soy proteins contain bioactive peptides with antioxidant properties, reduce cholesterol levels, have a hypotonic effect, and prevent thrombosis [123]. Wheat bran, with 13% to 18% protein content, is also a potential source for protein extraction, with high lysine and arginine content [124]. Furthermore, protein production from legume by-products has been explored by Prandi et al. (2021) [103].

2. **Protein Extraction Methods:** Many studies have shown that protein extraction involves a process of physical, chemical, or biochemical methods that aim to break down plant cells, thus releasing their contents or precipitating target proteins [68]. Extraction is widely used to obtain proteins, oils, aromatic compounds, and more, and it is involved in most industrial processes today [125]. Choosing the right extraction method is crucial in preserving the nutritional value of proteins, as harsh pH or temperature conditions can damage them [103]. Traditional extraction methods may not be sufficient in extracting all complex biopolymers, particularly proteins and polysaccharides [126]. Nevertheless, new eco-friendly technologies are emerging, which can positively impact the final product's properties [127].

   Over the past ten years, new techniques have emerged for extracting protein from natural sources. These methods include subcritical, microwave, ultrasound, and liquid- pressure extraction [128]. Enzyme preparations are also used for protein extraction [119]. For instance, Wubshet et al. (2018) and Lindberg et al. (2021) developed a method for obtaining protein from poultry by-products [85, 86]. In separate research papers, Özdemir (2022), Atef et al. (2020), Bredikhina et al. (2019), Zhang et al. (2020), Prandi et al. (2023), and Görgüç (2022) extracted proteins from various agricultural products using different enzymatic preparations [78, 87-89, 98, 125].

Caliceti et al. (2019), Gadalkar et al. (2019), and Ly et al. (2018) extracted proteins from defatted rice bran, watermelon seeds, from cauliflower leaves, respectively, using ultrasonic extraction [96, 97, 100]. Extraction by ultrasound method promises to improve the extraction process of metabolites from various food matrices [129]. Indeed, itis one of the 10 most popular methods used in food science [130]. Scientists have been exploring new ways to extract plant proteins from various food by-products. They have devised different techniques to produce protein isolate and hydrolysate depending on thetype of raw material and desired properties of the final product. The methods used includethermal, acid, and alkaline hydrolysis, but enzymatic hydrolysate production is becomingincreasingly popular. This method is sustainable and enables better control of themixtures' composition. [109].

Table 1 illustrates that protein extraction yields various protein ingredients: concentrate, isolate, and hydrolysate. Protein concentrate is achieved by eliminating non- protein elements, particularly carbohydrates, to heighten the protein concentration of the end product [131]. Protein isolate is produced by solubilizing protein in a salt solution ora medium with a pH far from the isoelectric point [132]. Protein hydrolyzate differs fromconcentrate and isolates because it combines small peptides and amino acids obtained from protein hydrolysis with enzymes, acids, alkaline processing, or fermentation [133]. Selecting the most appropriate protein extraction method requires considering factors such as raw material structure, processing time, cost, reproducibility, reliability, and finalproduct quality [66].

IV. CRICKET FLOUR – IS AN ALTERNATIVE SOURCE OF FOOD PROTEIN

It is essential to find sustainable options to ensure the safety of our food sources and protect the environment. Researchers have suggested using edible insects as a protein source that meets these criteria. Edible insects have gained particular interest due to their high protein content and low environmental impact [134]. Insect farming is cheaper than animal husbandry and has the advantage of rapid reproduction. Insects can feed throughout the year, regardless of the season, and most of their body is edible (80%). They also have rapid reproduction and growth rates. House crickets, for instance, have twice the protein conversion rate of chickens and four times the rate of cattle, according to researcher Imathiu [135]. Raising insects requires less land and water than raising livestock [136]. Obtaining 1 kg of products from worms and ants requires 2-10 times less land area than raising large horned cattle [137]. In addition, insects have very low greenhouse gas emissions [138]. According to researchers Oonincx and De Boer (2012), insect rearing requires much less energy than animal rearing [137]. Oibiokpa et al. (2018) studied termite (*Macrotermes nigeriensis*), cricket (*Gryllus assimilis*), grasshopper (*Melanoplus foedus*), and moth caterpillar (*Cirina forda*) for their protein content. Cricket was found to have the highest netprotein ratio (3.04), amino acid score (0.91), protein efficiency ratio (1.78), biological value (93.02%) and protein digestibility corrected for amino acid score (0.73) as compared to other insect proteins analyzed [139]. Recently, *Acheta domesticus*, a species of house cricket, has been developed commercially and used as bait in fisheries in the United States [140].

1. **Cricket Powder Composition:** Field crickets and house cricket species have been used as animal feed in agriculture for many years. Recently, researchers have been exploring the possibility of using these insects as a new human food source. The main component of house cricket is protein, and their diet affects the composition of their cricket flour. Research from a European clinic found that 100 grams of cricket flour contains 67.8 grams of protein, 5.5 grams of carbohydrates, 5.6 grams of fat, and 350 kilocalories of energy [141]. Montowska et al. (2019) also found that cricket flour contains 42.0-45.8% protein, and carbohydrates are mainly composed of multibranched polysaccharides of glucose in the form of glycogen, which is used as an energy source in the cricket's body when needed. Fat content ranges from 23.6% to 29.1% of dry matter and is a triglyceride energy source. Cricket powder is rich in minerals like calcium, magnesium, and iron. The copper, manganese, and zinc levels are especially high (2.33-4.51, 4.1-12.5, 12.8-21.8 mg/100 g of dry matter, respectively) [142]. House cricket also contains 7% crude fiber and is rich in chitin, which varies in proportion depending on the species and age of the cricket. For example, mature crickets contain 67.1-137.2 mg/kg of chitin [143]. Table 2 shows the average composition of cricket flour.

Table 2: The average composition of cricket flour

Protein (g/100 g)	**Fat (g/100 g)**	**Carbohydrate(g/100 g)**	**Fatty acids (g/100 g)**	**Ash (g/100 g)**	**Moisture (g/100 g)**	**Dietary fiber (g/100 g)**	**Chitin (g/100g)**	**Energy (kcal/100 g)**	**Reference**
74,0 - 78,0	9,0 – 12,0			≤ 5,6	3,0 – 6,0	8,0– 10,0	4,0-8,5		[145]
74.4-76.8	9.4-11.5	3.8-5	1.7-1.8	4.3-5.5	3.5 – 5.7	8.1-9.1	4.9-8	350-380	[146]
20,5	6,8			1,1	69,2			140,2	[147]
71.7	10.4	1.6		5.4	6.3	4.6			[148]

The quality of protein in food is determined by its ability to supply the necessary amino acids for body growth and maintenance, aswell as its digestibility [139]. Cricket flour provides all 20 naturally occurring amino acids, making it a source of both essential and non- essential amino acids (Table 3).

2. **Acceptance as a New Product and Safety:** Cricket One Co. Ltd submitted an application to the European Commission on 24th July 2019. They requested authorization to sell partially defatted powder made from *Acheta domesticus* (house cricket) as a novel food under Article 10(1) of Regulation (EU) 2015/2283. Based on this application, the European Food Safety Agency (EFSA) conducted a thorough study on cricket flour. The study showed that the powder has a high protein content due to chitin, a non-protein nitrogen. Chitin is an excellent source of insoluble fiber that remains intact in the human intestine without breaking down. The research team also noted that the amount of protein is high in the powder. Furthermore, as per the research team, there were no genotoxic effects of the product, and there have been no adverse effects in the past use of cricket products. It has been noted that individuals with a seafood allergy, especially to crustaceans, may also have an allergic reaction to *A. domesticus* protein. Furthermore, it is crucial to be aware that exposure to this protein can result in sensitization. They suggested that gluten might be present in the food given to the locusts and recommended further research on its potential as an allergen [145]. However, the European Agency for Food Safety (EFSA) of the Council of Europe has concluded that cricket powder produced under specific conditions by Cricket One Co. Ltd is safe and suitable for sale to the public. This decision was made on January 3, 2023, and the product will be added to the list of new products in the European Union [144]. Thailand, the world's largest cricket producer, has developed a standard for cricket farming that includes regulations for farm components, feed, water, animal health, environment, and record-keeping. The goal is to produce high-quality, safe crickets for consumers. Feed must be fresh, water must be uncontaminated, equipment must be clean and hygienic, and all chemicals must be used according to instructions [149].

3. **Microbiological Safety:** According to Walia et al. (2018), the safety of cricket flour depends on how the crickets were raised. If not raised under proper conditions, they can become harmful. Materials like egg cartons used to raise crickets can increase the risk of contamination with *Salmonella* and *Campylobacter*. The authors suggest boiling baby food enriched with grasshopper flour for five minutes to prevent harmful microorganisms like *Escherichia coli, Staphylococcus aureus, Bacillus cereus, Clostridium perfringens A*, and *Cronobacter sakazakii* [150]. Improper handling or storage of ready-to-eat feed can also make cricket feed or meals unsafe. For example, drying grasshoppers at low temperatures can cause the reproduction of pathogenic microorganism spores.

Table 3: Amino acid composition of cricket species (g/100 g)

Amino acid	***Acheta domesticus*****)** (big) [14]	***Acheta domesticus*** **)**(small) [14]	***Acheta domesticus*****)** (big) [15]	***G. bimaculatus*** [15]	***Acheta testacea Walker*** [16]
Valine	1.07	0.76	4.5	3.5	3.44
Isoleucine	0.94	0.66	2.9	2.35	2.98
Leucine	2.05	1.47	3.8	3.88	6.09
Lysine	1.1	0.83	3.22	2.89	4.61
Threonine	0.74	0.55	1.65	1.67	2.9
Tryptophan	0.13	0.08	0.43	0.27	2.44
Phenylalanine	0.65	0.43	2.38	2.24	6.24 (+Tyrosine)
Methionine	0.3	0.2	0.98	0.86	-
Histidine	0.48	0.34	1.72	1.57	1.54
Alanine	1.8	1.37	3.67	4.69	7.8
Aspartic acid	1.72	1.09	4.61 (+Asparagine)	2.87	6.9
Arginine	1.25	0.94	3.92	3.47	4.5
Cystine	0.17	0.13	0.40	0.38	-
Glycine	1.04	0.81	2.60	3.31	4.7
Glutamic acid	2.1	1.60	6.45 (+Glutamine)	6.77	9.68
Methionine + cysteine	0.47	0.33	-	-	3.09
Proline	1.1	0.85	-	-	4.52
Serine	1.0	0.64	-	-	3.59
Tyrosine	1.0	0.85	-	-	-
Taurine	141	8.10	-	-	-
Ammonia	0.36	0.23	-	-	-

4. **Application of Cricket Powder:** Researchers are currently exploring the potential of crickets as a source of biologically active compounds and a food ingredient. In a study conducted by Udomsil et al. (2019), cricket proteins were found to possess high water- holding capacity and emulsifying and foaming properties, making them suitable for meat and bakery products [147]. However, it was noted by Zhao et al. (2017) that cricket proteins are sensitive to environmental factors such as temperature, pH, protein concentration, and ionic strength [151]. Despite this, cricket flour has been found to be a good source of protein and fat, with valuable

technical-functional and antioxidant properties, and can be used to develop new food products [152]. Scientific studies have shown that crickets are a harmless and sustainable source of protein, making it a promising option for the future. Due to its emulsifying and foaming properties, it can also be used as a food additive to enhance the functionality of various food products such as baked goods, potato products, meat substitutes, flour-based snacks, soups, and soup concentrates.

V. CONCLUSION

Given the Earth's limited resources and the projected population growth, reaching up to 9.8 billion people by 2050, it is understandable that PM remains a significant concern. Nevertheless, there are potential strategies for addressing this issue through improved distribution methods, which can help alleviate problems related to protein deficiency and malnutrition. Prevention strategies include enhancing access to protein-rich foods, promoting education on balanced diets, early detection, and treatment. Agricultural development programs that improve the production and availability of protein-rich foods and promote sustainable practices can help combat PM. Dietary diversity and including livestock and aquaculture in agricultural systems are crucial for addressing nutrient deficiencies. A balanced diet that incorporates both animal and plant protein sources is essential. Obtaining protein from food by-products through traditional and innovative extraction methods is a cost-effective alternative. Additionally, reducing food waste is another measure that can be taken. Utilizing by-products from processing meat and poultry, fish, dairy, fruits, and vegetables, oilseeds, cereals, and legumes can provide an alternative source of protein. This approach promotes sustainability and environmental friendliness, highlighting the significance of food security and addressing the impact of limited resources on the ever- growing global population. Edible insects are an outstanding protein source for humans, as they contain various valuable nutrients such as chitin, calcium, magnesium, iron, copper, manganese, and zinc. For those unable to consume gluten, cricket powders are an excellent substitute for gluten proteins, providing high protein content. Notably, cricket flour can be used in various foods, including crackers, breadsticks, cereal bars, baked goods, sauces, pasta, and meat alternatives. By applying these approaches and other measures, such as reducing food waste and introducing alternative protein sources, PM can be addressed, and shortages of protein sources can be eliminated.

REFERENCES

[1] FAO Protein quality evaluation: report of an FAO/WHO Expert Consultation. FAO Food and Nutrition Paper 92, FAO, Rome (Italy), 2013
[2] FAO/WHO/UNU. Protein and Amino Acid Requirements in Human Nutrition: Report of a Joint FAO/WHO/UNU Expert Consultation (2002: Geneva, Switzerland). World Health Organization; WHO Technical Report Series, No 935; WHO: Geneva, Switzerland, 2007
[3] R. R. Wolfe, A. M. Cifelli, G. Kostas, and I. Y. Kim, "Optimizing protein intake in adults: interpretation and application of the recommended dietary allowance compared with the acceptable macronutrient distribution range," Adv. Nutr. 8.2, 2017, pp.266-275.

[4] H. C.Schönfeldt, and N. G. Hall, "Dietary protein quality and malnutrition in Africa," Br. J. Nutr. 108.S2, 2012, pp.S69-S76.
[5] WHO. Malnutrition. Available online: https://www.who.int/news-room/q-a-detail/malnutrition (accessed on31 July 2023).
[6] GHI. Global Hunger Index Scores by 2022 GHI Rank Available online: https://www.globalhungerindex.org/ranking.html (accessed on 31 July 2023).
[7] W. Guoyao, "Dietary protein intake and human health," Food Funct. 7.3, 2016, pp.1251-1265.
[8] WHO. Nutrition. Child malnutrition and mortality. World Health Statistics. Available online: https://www.who.int/data/gho/data/themes/topics/joint-child-malnutrition-estimates-unicef-who-wb#:~:text=In%202020%2C%20149.2%20million%20children,for%20their%20height%20(overweight)(accessed on 31 July 2023).
[9] A. J. Prendergast, and J. H. Humphrey, "The stunting syndrome in developing countries," Paediatr. int.child health 34.4 (2014): 250-265.
[10] R. E. Black, C. G. Victora, S. P. Walker, Z. A. Bhutta, P. Christian, M.De Onis, and R. Uauy, "Maternal and child undernutrition and overweight in low-income and middle-income countries," The lancet 382.9890, 2013, pp.427-451.
[11] M. De Onis, M. Blössner, and E. Borghi, "Prevalence and trends of stunting among pre-school children, 1990–2020," Public Health Nutr. 15.1, 2012, pp.142-148.
[12] M. H. N. Golden, "Is complete catch-up possible for stunted malnourished children?," Eur. J. Clin. Nutr. 48.1, 1994, pp. 58-71.
[13] C. G. Victora, L. Adair, C. Fall, P. C. Hallal, R. Martorell, L. Richter, and H. S. Sachdev, "Maternal and child undernutrition: consequences for adult health and human capital," The lancet 371.9609, 2008, pp.340-357.
[14] N. M. Mehta, M. R. Corkins, B. Lyman, A. Malone, P. S. Goday, J. L. Monczka, S. W. Plogsted, and W. F. Schwenk, "Defining pediatric malnutrition: a paradigm shift toward etiology-related definitions," J. Parenter. Enteral Nutr. 37.4, 2013, pp.460-481.
[15] World Health Organization. Management of Severe Malnutrition: A Manual for Physicians and Other Senior Health Workers. WHO; 1999. Available online: https://apps.who.int/iris/handle/10665/41999 (accessed on 31 July 2023).
[16] L. G. Mazzei, C. D. C. Bergamaschi, M. T. Silva, S. Barberato Filho, I. Fulone, M. D. G.Moura, C. Guimaraes, and L. C. Lopes, "Use of IMMPACT domains in clinical trials of acupuncture for chronic pain:A methodological survey," Plos one 15.4, 2020, pp. e0231444.
[17] M. Shahid, Y. Cao, M. Shahzad, R. Saheed, U. Rauf, M. G. Qureshi, and F. Ahmed, "Socio-economic and environmental determinants of malnutrition in under three children: Evidence from PDHS-2018," Children 9.3, 2022, pp.361.
[18] M. M. Black, A. H. Baqui, K. Zaman, L. Ake Persson, S. El Arifeen, K. Le, and R. E. Black, "Iron and zinc supplementation promote motor development and exploratory behavior among Bangladeshi infants," AJCN80.4, 2004, pp.903-910.
[19] S. Grantham-McGregor, Y. B. Cheung, S. Cueto, P. Glewwe, L. Richter, and B. Strupp, "Developmental potential in the first 5 years for children in developing countries," The lancet 369.9555, 2007, pp.60-70.
[20] Z. Grover, and L. C. Ee, "Protein energy malnutrition," Pediatr. Clin. 56.5, 2009, pp.1055-1068.
[21] C. Alberda, A. Graf, and L. McCargar, "Malnutrition: etiology, consequences, and assessment of a patient at risk," Best Pract Res Clin Gastroenterol. 20.3, 2006, pp.419-439.
[22] P. Balestrieri, M. Ribolsi, M. P. L. Guarino, S. Emerenziani, A. Altomare, and M. Cicala, "Nutritional aspects in inflammatory bowel diseases," Nutrients 12.2, 2020, pp.372.
[23] J. F. Ludvigsson, D. A. Leffler, J. C. Bai, F.Biagi, A. Fasano, P. H. Green, and C. Ciacci, "The Oslo definitions for coeliac disease and related terms," Gut 62.1, 2013, pp.43-52.
[24] M. Kerac, M. Mwangome, M. McGrath, R. Haider, and J. A. Berkley, "Management of acute malnutrition in infants aged under 6 months (MAMI): current issues and future directions in policy and research," Food Nutr Bull. 36.1_suppl1, 2015, pp.S30-S34.

[25] G. Kennedy, T. Ballard, M.C. Dop, United Nations, Food and Agriculture Organization, Guidelines for measuring household and individual dietary diversity. Rome, Italy. 2011.
[26] S. M. Phillips, "Dietary protein requirements and adaptive advantages in athletes," Br. J. Nutr. 108.S2, 2012, pp.S158-S167.
[27] A. Skalicky, A. F. Meyers, W. G. Adams, Z. Yang, J. T. Cook, and D. A. Frank, "Child food insecurity and iron deficiency anemia in low-income infants and toddlers in the United States," Matern. Child Health J. 10,2006, pp.177-185.
[28] WHO. Guidelines on food fortification with micronutrients. Available online: https://www.who.int/publications/i/item/9241594012 (accessed on 31 July 2023).
[29] T. Ahmed, M. Hossain, and K. I. Sanin, "Global burden of maternal and child undernutrition and micronutrient deficiencies," Ann. Nutr. Metab. 61.Suppl. 1, 2013, pp.8-17.
[30] W. Nidhi, K. Agho, and A. M. Renzaho, "Past drivers of and priorities for child undernutrition in South Asia: A mixed methods systematic review protocol," Syst. Rev. 8, 2019, pp.1-8.
[31] WHO. Data platform. Protein-energy malnutrition. Available online: https://platform.who.int/mortality/themes/theme-details/topics/indicator-groups/indicator-group-details/MDB/protein-energy-malnutrition (accessed on 31 July 2023).
[32] S. Bunker, and J. Pandey, "Educational case: understanding kwashiorkor and marasmus: diseasemechanisms and pathologic consequences," Acad. Pathol. 8, 2021, pp.23742895211037027.
[33] L. Gogra, J. Fallah, T. Muchee, and P. A. Bourne, "An Evaluation of Nutritional Status and Dietary Diversity of Under-five Children in Kroo Bay Community, Western Area Urban, Freetown, Sierra Leone," Int. J. Med. Med. Sci. Res. 6.1, 2023, pp.43-66.
[34] E. Grellety, and M. H. Golden, "Severely malnourished children with a low weight-for-height have similar mortality to those with a low mid-upper-arm-circumference: II. Systematic literature review and meta- analysis," Nutr. J. 17, 2018, pp.1-19.
[35] O. Benjamin, and S. L. Lappin. "Kwashiorkor." StatPearls [Internet]. StatPearls Publishing, 2022.
[36] P. C. Dagnelie, M. Van Dusseldorp, W. A. Van Staveren, and J. G. Hautvast, "Effects of macrobiotic diets on linear growth in infants and children until 10 years of age," Eur. J. Clin. Nutr. 48, 1994, pp.S103-11.
[37] A. Bender, Meat and meat products in human nutrition in developing countries. Food and Agriculture Organization of the United Nations (FAO) Food and Nutrition Papers, vol. 53. 1992.
[38] R. S. Gibson, "Content and bioavailability of trace elements in vegetarian diets," Am. J. Clin. Nutr. 59.5, 1994, pp.S1223-S1232.
[39] D. I. Givens, "The role of animal nutrition in improving the nutritive value of animal-derived foods in relation to chronic disease," Proc. Nutr. Soc. 64.3, 2005, pp.395-402.
[40] FAO. FAOSTAT Statistics Division. Protein consumption (Indicator). Available online: https://www.fao.org/faostat/en/#search/Protein%20consumption (accessed on 31 July 2023).
[41] WHO child growth standards and the identification of severe acute malnutrition in infants and children. A Joint Statement Available online: https://www.who.int/publications/i/item/9789241598163 (accessed on 31July 2023).
[42] D. Layman, "The changing roles and understanding about dietary protein for life-long health, " Foredraget blev holdt den. 2010;21.
[43] D. Pieniaźek, M. Rakowska, W. Szkiłładziowa, and Z. Grabarek, "Estimation of available methionine and cysteine in proteins of food products by in vivo and in vitro methods," Br. J. Nutr. 34.2, 1975, pp.175-190.
[44] R. F. Hurrell, "Influence of vegetable protein sources on trace element and mineral bioavailability." J. Nutr.133.9, 2003, pp.2973S-2977S.
[45] B. Thompson, and J. Meerman. "Narrowing the nutrition gap: Investing in agriculture to improve dietary diversity." Proceedings of the International Symposium on Food and Nutrition Security: Foodbased Approaches for Improving Diets and Raising Levels of Nutrition. Rome, Italy: FAO, 2010.
[46] C. Neumann, D. M. Harris, and L. M. Rogers, "Contribution of animal source foods in improving

diet quality and function in children in the developing world," Nutr. Res. 22.1-2, 2002, pp.193-220.
[47] B. X., Lee, F. Kjaerulf, S. Turner, L. Cohen, P. D. Donnelly, R. Muggah, and J. Gilligan, "Transforming our world: implementing the 2030 agenda through sustainable development goal indicators," J. Public Health Policy 37, 2016, pp.13-31.
[48] X. Li, R. Yadav, and K. H. Siddique, "Neglected and underutilized crop species: the key to improving dietary diversity and fighting hunger and malnutrition in Asia and the Pacific," Front. Nutr. 7, 2020, pp.593711.
[49] M. N. Fairulnizal, M. K. Norhayati, A. Zaiton, A. H. Norliza, S. Rusidah, A. R. Aswir and T. M. Zainuldin, "Nutrient content in selected commercial rice in Malaysia: An update of Malaysian food composition database," Int. Food Res. J. 2, 2015, pp.768.
[50] Z. A. Bhutta, T. Ahmed, R. E. Black, S. Cousens, K. Dewey, E. Giugliani, and M. Shekar, "What works? Interventions for maternal and child undernutrition and survival." The lancet 371.9610, 2008, pp.417-440.
[51] World Health Organization. Indicators for Assessing Infant and Young Child Feeding Practices Part 3: Country Profiles; World Health Organization: Geneva, Switzerland, 2010.
[52] S. Ip, M. Chung, G. Raman, P. Chew, N. Magula, D. DeVine, and J. Lau, "Breastfeeding and maternal and infant health outcomes in developed countries," Evidence report/technology assessment 153, 2007, pp.1- 186.
[53] D. J. Raiten, L. H. Allen, J. L. Slavin, F. M. Mitloehner, G. J. Thoma, P. A. Haggerty, and J. W. Finley, "Understanding the intersection of climate/environmental change, health, agriculture, and improved nutrition: a case study on micronutrient nutrition and animal source foods," Curr. Dev. Nutr. 4.7, 2020, nzaa087.
[54] M. Arimond, and M. T. Ruel, "Dietary diversity is associated with child nutritional status: evidence from 11demographic and health surveys," J. Nutr. 134.10, 2004, pp.2579-2585.
[55] A. M. Williams, and P. S. Suchdev, "Assessing and improving childhood nutrition and growth globally," Pediatr. Clin. 64.4, 2017, pp.755-768.
[56] C. Kubrak, and L. Jensen, "Malnutrition in acute care patients: a narrative review," Int. J. Nurs. Stud. 44.6, 2007, pp.1036-1054.
[57] E. Van de Poel, A. R. Hosseinpoor, C. Jehu-Appiah, J. Vega, and N. Speybroeck, "Malnutrition and the disproportional burden on the poor: the case of Ghana," Int. J. Equity Health 6.1, 2007, pp.1-12.
[58] A. C. Ubesie, and N. S. Ibeziakor, "High burden of protein–energy malnutrition in Nigeria: Beyond the health care setting," Ann. Med. Health sci. Res. 2.1, 2012, pp.66-69.
[59] M. Béhar, F. Viteri, R. Bressani, G. Arroyave, R. L. Squibb, and N. S. Scrimshaw, "Principles of treatment and prevention of severe protein malnutrition in children (kwashiorkor)." Ann. N. Y. Acad. Sci. 69.5, 1958,pp.954-968.
[60] S. Brownie, & R. Coutts, "Older Australians' perceptions and practices in relation to a healthy diet for old age: A qualitative study," J. Nutr. Health Aging 17, 2013, pp.125-129.
[61] S. Rousset, S.Droit-Volet, and Y. Boirie, "Change in protein intake in elderly French people living at home after a nutritional information program targeting protein consumption," J. Am. Diet. Assoc. 106.2, 2006, pp.253-261.
[62] G. Scholes, "Protein-energy malnutrition in older Australians: A narrative review of the prevalence, causes and consequences of malnutrition, and strategies for prevention," Health Promot. J. Austr. 33.1, 2022, pp.187-193.
[63] WHO. Malnutrition: the global picture. Available online: https://www.who.int/health-topics/malnutrition#tab=tab_1 (accessed on 31 July 2023).
[64] H. Bürgi, Z. Supersaxo, and B. Selz, "Iodine deficiency diseases in Switzerland one hundred years after Theodor Kocher's survey: a historical review with some new goitre prevalence data," Eur. J. Endocrinol. 123.6, 1990, pp.577-590.
[65] D. Marine, and O. P. Kimball, "Prevention of simple goiter in man: fourth paper," Arch. Intern.

Med. 25.6, 1920, pp.661-672.
[66] E. Gençdağ, A. Görgüç, and F. M. Yılmaz, "Recent advances in the recovery techniques of plant-based proteins from agro-industrial by-products," Food Rev. Int. 37.4, 2021, pp.447-468.
[67] FAO. Food Wastage Footprint - Impacts on Natural Resources (2013). Available online: http://www.fao.org/docrep/018/i3347e/ (accessed on 31 July 2023)
[68] M. L. Segatto, A. M. Stahl, K. Zanotti, and V. G. Zuin, "Green and sustainable extraction of proteins from agro-industrial waste: An overview and a closer look to Latin America," Curr. Opin. Green Sustain. Chem. 2022, pp.100661.
[69] B. Kumari, B. K. Tiwari, M. B. Hossain, N. P. Brunton, and D. K. Rai, "Recent advances on application of ultrasound and pulsed electric field technologies in the extraction of bioactives from agro-industrial by- products," Food Bioproc. Tech. 11, 2018, pp.223-241.
[70] I. M. Abu-Reidah, D. Arráez-Román, I.Warad, A. Fernández-Gutiérrez, and A.Segura-Carretero, "UHPLC/MS2-based approach for the comprehensive metabolite profiling of bean (Vicia faba L.) by- products: A promising source of bioactive constituents," Food Res. Int. 93, 2017, pp.87-96.
[71] R. Gómez-García, D. A.Campos, C. N. Aguilar, A. R. Madureira, and M. Pintado, "Valorisation of food agro-industrial by-products: From the past to the present and perspectives," J. Environ. Manage. 299, 2021,pp.113571.
[72] A. Görgüç, C. Bircan, and F. M. Yılmaz, "Sesame bran as an unexploited by-product: Effect of enzyme andultrasound-assisted extraction on the recovery of protein and antioxidant compounds," Food Chem. 283, 2019, pp.637-645.
[73] A. G. A. Sá, Y. M. F. Moreno, and B. A. M. Carciofi, "Plant proteins as high-quality nutritional source for human diet," Trends Food Sci. Technol. 97, 2020, pp.170-184.
[74] M. J. Boland, A. N. Rae, J. M. Vereijken, M. P. Meuwissen, A. R. Fischer, M. A. van Boekel, and W. H. Hendriks, "The future supply of animal-derived protein for human consumption." Trends Food Sci. Technol. 29.1, 2013, pp.62-73.
[75] C. Boyle, L. Hansen, C. Hinnenkamp, and B. P. Ismail, "Emerging camelina protein: Extraction, modification, and structural/functional characterization," J. Am. Oil Chem. Soc. 95.8, 2018, pp.1049-1062.
[76] D. Ananey-Obiri, L. G., Matthews, and R. Tahergorabi, "Proteins from fish processing by-products." Proteins: Sustainable source, processing and applications. Academic Press, 2019, pp.163-191.
[77] A. C. Lemes, L. Sala, J. D. C. Ores, A. R. C. Braga, M. B. Egea, and Fernandes, K. F. "A review of the latest advances in encrypted bioactive peptides from protein-rich waste." Int. J. Mol. Sci. 17.6, 2016, pp.950.
[78] E. E. Özdemir, A. Görgüç, E. Gençdağ, and F. M. Yılmaz, "Physicochemical, functional and emulsifying properties of plant protein powder from industrial sesame processing waste as affected by spray and freeze drying," LWT 154, 2022, pp.112646.
[79] H. Axel, G. Thomas, V.V. Volkov, O. Ya. Mezenova, and N. Yu. Mezenova, "Innovative production of proteins from protein-containing biological raw materials," Bulletin of Science and Education of the North-West of Russia 3.2, 2017, pp.56-67. (in Russian).
[80] E. M. Nuutinen, P. Willberg-Keyriläinen, T. Virtanen, A. Mija, L. Kuutti, R. Lantto, and A. S. Jääskeläinen, "Green process to regenerate keratin from feathers with an aqueous deep eutectic solvent," RSC Adv. 9.34, 2019, pp.19720-19728.
[81] B. Mu, F. Hassan, and Y. Yang, "Controlled assembly of secondary keratin structures for continuous and scalable production of tough fibers from chicken feathers," Green Chem. 22.5, 2020, pp.1726-1734.
[82] S. Cao, Y. Wang, L. Xing, W. Zhang, and G. Zhou, "Structure and physical properties of gelatin from bovine bone collagen influenced by acid pretreatment and pepsin," Food Bioprod. Process. 121, 2020, pp.213-223.
[83] X. Mi, W. Li, H. Xu, B. Mu, Y. Chang, and Y.Yang, "Transferring feather wastes to ductile keratin filaments towards a sustainable poultry industry," Waste Manag. 115, 2020, pp.65-73.

[84] S. G. Wubshet, J. P. Wold, N. K. Afseth, U. Böcker, D. Lindberg, F. N. Ihunegbo, and I. Måge, "Feed- forward prediction of product qualities in enzymatic protein hydrolysis of poultry by-products: A spectroscopic approach," Food Bioproc. Tech. 11, 2018, pp.2032-2043.

[85] D. Lindberg, K. A. Kristoffersen, S. G. Wubshet, L. M. G. Hunnes, M. Dalsnes, K. R. Dankel, and N. K. Afseth, "Exploring effects of protease choice and protease combinations in enzymatic protein hydrolysis of poultry by-products," Molecules 26.17, 2021, pp.5280.

[86] L. V. Antipova, S. A. Storublevtsev, M. A. Piskova, and Yu. Z. Himishev, "Protein resources of fish origin- a source of health and beauty," Bulletin of the Voronezh State University of Engineering Technologies 80.4 (78), 2018, pp.138-144. (in Russian).

[87] M. Atef, S. M. Ojagh, A. M. Latifi, M. Esmaeili, and C. C. Udenigwe, "Biochemical and structural characterization of sturgeon fish skin collagen (Huso huso)," J. Food Biochem. 44.8, 2020, pp.e13256.

[88] O. V. Bredikhina, I. N. Igonina, N. Yu. Zarubin, S. N. Kidyaev, and E. V. Litvinova, "The use of waste from squid processing to obtain a protein hydrolyzate and a polyfunctional food complex on its basis," Fisheries 4, 2019, pp.99-105. (in Russian).

[89] X. Zhang, H. Zhang, S. Toriumi, K. Ura, and Y. Takagi, "Feasibility of collagens obtained from bester sturgeon Huso huso× Acipenser ruthenus for industrial use," Aquaculture 529, 2020, pp.735641.

[90] J. A. Parrón, D. Ripollés, F. Navarro, S. J. Ramos, M. D. Pérez, M. Calvo, and L. Sánchez, "Effect of high pressure treatment on the antirotaviral activity of bovine and ovine dairy by-products and bioactive milk proteins," Innov. Food Sci. Emerg. Technol. 48, 2018, pp.265-273.

[91] P. Nicolás, M. L. Ferreira, and V. Lassalle, "A review of magnetic separation of whey proteins and potentialapplication to whey proteins recovery, isolation and utilization," J. Food Eng. 246, 2019, pp.7-15.

[92] R. Domínguez-Puerto, S. Valle-Guadarrama, D. Guerra-Ramírez, and F.Hahn-Schlam, "Purification and concentration of cheese whey proteins through aqueous two phase extraction," CYTA J. Food 16.1, 2018, pp.452-459.

[93] K. Ryder, M. A. Ali, J. Billakanti, and A. Carne, "Fundamental characterisation of caseins harvested by dissolved air flotation from dairy wastewater and comparison with skim milk powder." Int. Dairy J. 78, 2018, pp.112-121.

[94] A. H. Martin, O. Castellani, G. A. de Jong, L. Bovetto, and C. Schmitt, "Comparison of the functional properties of RuBisCO protein isolate extracted from sugar beet leaves with commercial whey protein and soy protein isolates," J. Sci. Food Agric. 99.4, 2019, pp.1568-1576.

[95] T. Sedlar, J. Čakarević, J. Tomić, and L. Popović, "Vegetable by-products as new sources of functional proteins," Plant Foods Hum. Nutr. 76, 2021, pp.31-36.

[96] C. Caliceti, A. L. Capriotti, D. Calabria, F. Bonvicini, R. Zenezini Chiozzi, C. M. Montone, and A. Roda, "Peptides from cauliflower by-products, obtained by an efficient, ecosustainable, and semi-industrial method, exert protective effects on endothelial function," Oxid. Med. Cell. Longev. Special Issue, 2019, pp.1-13.

[97] S. M. Gadalkar, and V. K. Rathod, "Extraction of watermelon seed proteins with enhanced functional properties using ultrasound," Prep. Biochem. Biotechnol. 50.2, 2020, pp.133-140.

[98] B. Prandi, I. M. Cigognini, A. Faccini, C. Zurlini, Ó. Rodríguez, and T. Tedeschi, "Comparative Study of Different Protein Extraction Technologies Applied on Mushrooms By-products," Food Bioproc. Tech. 2023, pp.1-12.

[99] M. Dabbour, R. He, H. Ma, and A. Musa, "Optimization of ultrasound assisted extraction of protein from sunflower meal and its physicochemical and functional properties," J. Food Process Eng. 41.5, 2018, pp.e12799.
[100] H. L Ly, T. M. Tran, C. T. T. T. Tran, N. M. N. Ton, and V. V. M. Le, "Application of ultrasound to protein extraction from defatted rice bran," Int. Food Res. J. 25.2, 2018, pp.695-701.
[101] J. Y. Chua, and S. Q. Liu, "Soy whey: More than just wastewater from tofu and soy protein isolate industry," Trends Food Sci. Technol. 91, 2019, pp.24-32.
[102] N. T. Alzuwaid, M. Sissons, B. Laddomada, and C. M. Fellows, "Nutritional and functional properties of durum wheat bran protein concentrate," Cereal Chem. 97.2, 2020, pp.304-315.
[103] B. Prandi, C. Zurlini, C. I. Maria, S. Cutroneo, M. Di Massimo, M. Bondi, and T. Tedeschi, "Targeting the nutritional value of proteins from legumes by-products through mild extraction technologies." Front. Nutr.8, 2021, pp.695793.
[104] C. Anzani, F. Boukid, L. Drummond, A. M. Mullen, and C. Álvarez, "Optimising the use of proteins from rich meat co-products and non-meat alternatives: Nutritional, technological and allergenicity challenges," Food Res. Int. 137, 2020, pp.109575.
[105] E. V. Kostyleva, A. S. Sereda, I. A. Velikoretskaya, E. I. Kurbatova, and N. V. Tsurikova, (2023). "Use of proteolitic enzymes for obtaining protein hydrolyzates for food purpose from secondary raw materials," Nutr. Rev. 92.1, (545), 2023, pp.116-132. (in Russian).
[106] A. León-López, A. Morales-Peñaloza, V. M. Martínez-Juárez, A. Vargas-Torres, D. I. Zeugolis, and G. Aguirre-Álvarez, "Hydrolyzed collagen—Sources and applications," Molecules 24.22, 2019, pp.4031.
[107] A. Shavandi, T. H. Silva, A. A. Bekhit, and A. E. D. A. Bekhit, "Keratin: dissolution, extraction and biomedical application," Biomater. Sci. 5.9, 2017, pp.1699-1735.
[108] A. K. Gulevsky, and I. I. Shcheniavsky, "Collagen: Structure, metabolism, production and industrial application." Biotechnol. Acta 13.5, 2020, pp.42-61.
[109] S. Timorshina, E. Popova, and A. Osmolovskiy, "Sustainable applications of animal waste proteins." Polymers 14.8, 2022, pp.1601.
[110] A. F. Pires, N. G. Marnotes, O. D. Rubio, A. C. Garcia, and C. D. Pereira, "Dairy by-products: A review on the valorization of whey and second cheese whey," Foods 10, 2021, pp.1067.
[111] C. Blecker, M. Paquot, I. Lamberti, A. Sensidoni, G. Lognay, and C. Deroanne, "Improved emulsifying and foaming of whey proteins after enzymic fat hydrolysis," J. Food Sci. 62.1, 1997, pp.48-52.
[112] H. Deeth, and N. Bansal, "Whey proteins: An overview," Whey proteins 2019, pp.1-50.
[113] B. C. Ghosh, L. N. Prasad, and N. P. Saha, "Enzymatic hydrolysis of whey and its analysis," J. Food Sci. Technol. 54, 2017, pp.1476-1483.
[114] F. Dilucia, V. Lacivita, A. Conte, and M. A. Del Nobile, "Sustainable use of fruit and vegetable by- products to enhance food packaging performance," Foods 9.7, 2020, pp.857.
[115] M. A. Malik, and C. S. Saini, "Improvement of functional properties of sunflower protein isolates near isoelectric point: Application of heat treatment," LWT - Food Sci. Technol. 98, 2018, pp.411-417.
[116] S. González-Pérez, and J. M. Vereijken, "Sunflower proteins: overview of their physicochemical, structural and functional properties," J. Sci. Food Agric. 87.12, 2007, pp.2173-2191.
[117] M. Verni, C. G. Rizzello, and R. Coda, "Fermentation biotechnology applied to cereal industry by- products: Nutritional and functional insights," Front. Nutr. 6, 2019, pp.42.
[118] N. D. Brier, S. V. Gomand, E. Donner, D. Paterson, J. A. Delcour, E. Lombi, and E. Smolders, "Distribution of minerals in wheat grains (Triticum aestivum L.) and in roller milling fractions affected bypearling," J. Agric. Food Chem. 63.4, 2015, pp.1276-1285.
[119] V. G. Kulakov, and S. V. Kapustin, "The use of extracted proteins from vegetable raw materials

in functional and specialized nutrition," Vegetables of Russia 5, 2018, pp.84-87. (in Russian).
[120] S. Benedetti, E. S. Prudêncio, G. L. Nunes, K. Guizoni, L. A. Fogaça, and J. C. C. Petrus, "Antioxidant properties of tofu whey concentrate by freeze concentration and nanofiltration processes," J. Food Eng. 160, 2015, pp.49-55.
[121] Y. Xiao, L. Wang, X. Rui, W. Li, X. Chen, M. Jiang, and M. Dong, "Enhancement of the antioxidant capacity of soy whey by fermentation with Lactobacillus plantarum B1–6," J. Funct. Foods 12, 2015, pp.33-44.
[122] Y. Liang, Y. Guo, Y. Zheng, S. Liu, T. Cheng, L. Zhou, and Z. Guo, "Effects of high-pressure homogenization on physicochemical and functional properties of enzymatic hydrolyzed soybean protein concentrate," Front. Nutr. 9, 2022, pp.1054326.
[123] C. Chatterjee, S. Gleddie, and C. W. Xiao, "Soybean bioactive peptides and their functional properties," Nutrients 10.9, 2018, pp.1211.
[124] S. Apprich, Ö. Tirpanalan, J. Hell, M. Reisinger, S. Böhmdorfer, S. Siebenhandl-Ehn, and W. Kneifel, "Wheat bran-based biorefinery 2: Valorization of products," LWT - Food Sci. Technol. 56.2, 2014, pp.222-231.
[125] A. Görgüç, E. Gençdağ, and F. M. Yılmaz, "Optimization of microwave assisted enzymatic extraction of steviol glycosides and phenolic compounds from Stevia leaf," Acta Period. Technol. 50, 2019, pp.69-76.
[126] S. Gharib-Bibalan, "High Value-added products recovery from sugar processing by-products and residuals by green technologies: Opportunities, challenges, and prospects," Food Eng. Rev. 10, 2018, pp.95-111.
[127] P. Bradu, A. Biswas, C. Nair, S. Sreevalsakumar, M. Patil, S. Kannampuzha, and A. V. Gopalakrishnan, "Recent advances in green technology and Industrial Revolution 4.0 for a sustainable future," Environ. Sci.Pollut. Res. 2022, pp.1-32.
[128] S. C. Ndlela, J. M. L. N. De Moura, N. K. Olson, and L. A. Johnson, "Aqueous extraction of oil and protein from soybeans with subcritical water," J. Am. Oil Chem. Soc. 89, 2012, pp.1145-1153.
[129] E. Roselló-Soto, F. J. Barba, O. Parniakov, C. M. Galanakis, N. Lebovka, N. Grimi, and E. Vorobiev, "High voltage electrical discharges, pulsed electric field, and ultrasound assisted extraction of protein and phenolic compounds from olive kernel," Food Bioproc. Tech. 8, 2015, pp.885-894.
[130] C. M. Galanakis, "Emerging technologies for the production of nutraceuticals from agricultural by- products: a viewpoint of opportunities and challenges," Food Bioprod. Process. 91.4, 2013, pp.575-579.
[131] I. M. Rodrigues, J. F. Coelho, and M. G. V. Carvalho, "Isolation and valorisation of vegetable proteins from oilseed plants: Methods, limitations and potential," J. Food Eng. 109.3, 2012, pp.337-346.
[132] A. S. Grandison, and M. J. Lewis, (Eds.). Separation processes in the food and biotechnology industries: principles and applications. Elsevier, 1996.
[133] B. H. Sarmadi, and A. Ismail, "Antioxidative peptides from food proteins: A review," Peptides 31.10, 2010, pp.1949-1956.
[134] C. da Rosa Machado, and R. C. S. Thys, "Cricket powder (Gryllus assimilis) as a new alternative protein source for gluten-free breads," Innov. Food Sci. Emerg. Technol. 56, 2019, pp.102180.
[135] S. Imathiu, "Benefits and food safety concerns associated with consumption of edible insects," NFS journal 18, 2020, pp.1-11.
[136] D. Dobermann, J. A. Swift, and L. M. Field, "Opportunities and hurdles of edible insects for food and feed," Nutr. Bull. 42.4, 2017, pp.293-308.
[137] D. G. Oonincx, and I. J. De Boer, "Environmental impact of the production of mealworms as a protein source for humans–a life cycle assessment," PloS one 7.12, 2012, pp.e51145.
[138] D. G. Oonincx, J. Van Itterbeeck, M. J. Heetkamp, H. Van Den Brand, J. J. Van Loon, and A. Van Huis, "An exploration on greenhouse gas and ammonia production by insect species suitable for animal or human consumption," PloS one 5.12, 2010, pp.e14445.

[139] F. I. Oibiokpa, H. O. Akanya, A. A. Jigam, A. N. Saidu, and E. C. Egwim, "Protein quality of four indigenous edible insect species in Nigeria," Food Sci. Hum. Wellness 7.2, 2018, pp.175-183.

[140] J. A. Morales-Ramos, M. G. Rojas, A. T. Dossey, and M. Berhow, "Self-selection of food ingredients and agricultural by-products by the house cricket, Acheta domesticus (Orthoptera: Gryllidae): A holistic approach to develop optimized diets," PLoS One 15.1, 2020, pp.e0227400.

[141] C. L. R. Payne, P. Scarborough, M. Rayner, and K. Nonaka, "Are edible insects more or less 'healthy'than commonly consumed meats? A comparison using two nutrient profiling models developed to combat over-and undernutrition," Eur. J. Clin. Nutr. 70.3, 2016, pp.285-291.

[142] M. Montowska, P. Ł. Kowalczewski, I. Rybicka, and E. Fornal, "Nutritional value, protein and peptide composition of edible cricket powders," Food Chem. 289, 2019, pp.130-138.

[143] M. Psarianos, S. Ojha, R. Schneider, and O. K. Schlüter, "Chitin isolation and chitosan production from house crickets (Acheta domesticus) by environmentally friendly methods," Molecules 27.15, 2022, pp.5005.

[144] Commission Implementing Regulation (EU) 2023/5 of 3 January 2023 authorising the placing on the market of *Acheta domesticus* (house cricket) partially defatted powder as a novel food and amending Implementing Regulation (EU) 2017/2470 Official Journal of the European Union L 2/9.

[145] D. Turck, T. Bohn, J. Castenmiller, S. De Henauw, K. I. Hirsch-Ernst, and H. K. Knutsen, "Safety of partially defatted house cricket (Acheta domesticus) powder as a novel food pursuant to Regulation (EU) 2015/2283." EFSA Journal 20.5, 2022, e07258. EFSA Panel on Nutrition, Novel Foods and Food Allergens (NDA).

[146] M. D. Finke, "Complete nutrient composition of commercially raised invertebrates used as food for insectivores," Zoo biology: published in affiliation with the American zoo and aquarium association 21.3, 2002, pp.269-285.

[147] N.Udomsil, S. Imsoonthornruksa, C. Gosalawit, and M. Ketudat-Cairns, "Nutritional values and functional properties of house cricket (Acheta domesticus) and field cricket (*Gryllus bimaculatus*)," Food Sci.Technol. Res. 25.4, 2019, pp.597-605.

[148] J. Yhoung-Aree, "Edible insects in Thailand: Nutritional values and health concerns. Forest insects as food: Humans bite back." Proceedings of a workshop on Asia-Pacific resources and their potential for development, Thailand. 2008.

[149] ACFS. Good Agricultural Practices for Cricket Farm; National Bureau of Argricultural Commodity and Food Standards, Ed.; Royal Gazette: Bangkok, Thailand, 2017; Volume 134, Special Section 293 D.

[150] K. Walia, A. Kapoor, and J. M. Farber, "Qualitative risk assessment of cricket powder to be used to treat undernutrition in infants and children in Cambodia," Food Control 92, 2018, pp.169-182.

[151] L. Q. Zhao, H. L. Chai, and D. H. Zhu, "Potential reproductive advantage of short-over long-winged adult males of the cricket Velarifictorus ornatus," Evol. Biol. 44, 2017, pp.91-99.

[152] R. Lucas-González, J. Fernández-López, J. A. Pérez-Álvarez, and M. Viuda-Martos, "Effect of drying processes in the chemical, physico-chemical, techno-functional and antioxidant properties of flours obtained from house cricket (*Acheta domesticus*)," Eur. Food Res. Technol. 245.7, 2019, pp.1451-1458.