ISSN 2959-409X

Progress in the study of nutrient composition and biological functions of locusts

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Abstracts:

In recent years, the expansion of the scope and intensity of insect nutrient source development has been consistent. Notably, locusts, recognized as a superior nutritional source, have garnered significant research attention and exploration. Gradually, their nutritional components and biological functions have been exploited and utilized. Primarily, the food value of locusts lies in the abundance of nutrients within their bodies. Nutritional composition studies on locusts date back to the 1970s, with numerous experiments validating their status as a novel food resource, rich in protein and low in fat and carbohydrates. Furthermore, they serve as an alternative resource for promoting health and wellness. Since the dawn of the 21st century, certain studies have revealed the presence of flavonoids, chitin, and other bioactive ingredients in locusts. This paper compiles and summarizes the primary nutrients and their respective concentrations in certain locust species, exploring the advancements and potential value of current research on their biological functions. The aim is to highlight the advantages of locusts as an innovative food resource.

Keywords: locust, nutrients, content determination, bioactive substances, food source fof

1. Introduction:

In recent years, the scope and intensity of insect nutrient source development have experienced varying degrees of expansion across different countries. On one hand, the escalating global population has rendered traditional resource supplies insufficient to meet the demands of daily life, necessitating the exploration and development of novel resources like insects, oceans, and fungi. On the other hand, in the post-epidemic era, individuals have become increasingly mindful of the nutritional content of their daily diets, leading to a growing market demand for low-fat, green, and healthy food products[1]. Locusts, esteemed as a superior nutritional source, have garnered significant research attention and their nutritional composition and biological functions have been progressively explored and utilized[2].

The food value of locusts primarily lies in the rich nutrients present in their bodies. Research into the nutritional composition of locusts dates back to the 1970s, with Aitkins documenting their high nutritional value in his book, "Insect Prospects"[3]. In the 1990s, research on the nutritional composition of locusts progressed further. Wang's study revealed that locusts contain a remarkable protein content of 74.88%, a low fat content of 5.25%, and a carbohydrate content of 4.77%[4]. Consequently, locusts emerge as a novel food resource, offering a high-protein, low-fat, and low-carbohydrate option, serving as an alternative for health and wellness-oriented foods.

Entering the 21st century, studies have uncovered that locusts also possess a certain amount of flavonoids, chitin, and other biologically active components. However, current research efforts are primarily focused on exploring a specific type of nutrient or active substance within locusts, limiting our comprehensive understanding of their nutritional profile. In contrast, this paper compiles and summarizes the key nutrients and their concentrations across various locust species. It further delves into the roles and functions of the biofunctional factors extracted from locusts. Additionally, by comparing the indices of the locust industry with those of the traditional food processing industry, this paper uses data to intuitively highlight the advantages of locusts as a novel food resource.

2. Studies on the nutritional composition of locusts

2.1 Proteins

2.1.1 Protein content

In earlier locust studies, Wang showed that the protein content in locusts was about 74.88 per cent (this value is the proportion of protein content to dry weight, same below)[4]. Duan analyzed the protein content of 10 species of locusts and came up with the result that the average protein content of locusts is 61.98±4.56%[5].

Table 1 Protein content of different locust species[5-7] (g/100g dry w t)

Species	Protein content (%)	Species	Protein content (%)
Oedaleus infernalis Saussure	65.91	Shirakiacris shirakii	67.68
Oedaleus decorus asiaticus	67.23	Atractomorpha sinensis	64.47
Acrida cinerea	68.33	Hieroglyphus banian Fabricius	63.61
Oxya chinensis Thunberg	62.06	Acrida exaltata Walker	64.46
Calliptamus abbreviatus	58.80	Chorthippus fallax	63.72
Spathosternum prasiniferum	65.88	Locusta migratoria manilensis	66.81
Trilophidia annulata	78.05	Aiolopus tamulus	66.92
Chorthippus albonemus	75.51	Chorthippus Fieber	65.79
Angaracris rhodopa	62.42	Acrida cinerea Thunb	62.76

Table 1 summarizes the protein content of several different species of locusts that have been measured, and it can be seen from the table that the protein content of the eighteen species of locusts is higher than 55% of the dry matter, which meets the criteria for the development of edible insects, and has a certain value for development. Although there are some differences in the protein content of different species, the overall difference is not significant. Among them, Trilophidia annulata has the highest content of 78.05%. The lowest Calliptamus abbreviatus can also reach 58.80 per cent. The protein content of several major edible locusts (Oxya chinensis Thunberg, Locusta migratoria manilensis and Acrida cinerea) is above 60 per cent.

Table 2 Composition and content of Amino acids of locusts [6-8]

Amino acid	Oxya chinensis Thunberg	Acrida cinerea	Locusta migratoria manilensis	average value	FAO Pattern	amino acid partition
Asp	4.143	4.083	4.443	4.223		
Thr*	2.04	2.105	2.315	2.153	4	0.538
Ser	2.229	2.232	2.282	2.247		
Glu	6.87	6.754	7.446	7.023		
Pro	2.564	2.825	2.88	2.756		
Gly	3.133	3.526	3.595	3.418		
Ala	6.193	6.882	6.945	6.673		
Val*	3.886	3.519	3.483	3.629	5	0.726
Cys	0.358	0.2989	0.3292	0.329	(Met+Cys) 3.5	0.412
Met*	0.9558	1.097	1.312	1.122		
Ile*	2.166	2.164	2.39	2.24	4	0.56
Leu*	4.465	4.537	4.881	4.628	7	0.661
Tyr	6.119	5.715	6.474	6.103	(Phe+Tyr) 6	1.371
Phe *	2.033	2.095	2.238	2.122		
Lys*	3.782	3.852	4.008	3.881	5.5	0.706

his	1.785	1.654	1.718	1.719		
Arg	3.632	3.687	3.991	3.7		

Note: * indicates essential amino acids

According to the 1973 World Food and Agriculture Organization (FAO) Amino Acid Scoring Model, essential amino acids in the measured food protein are compared with those in the reference protein, and the lowest ratio is the limiting amino acid. The presence of limiting amino acids restricts the utilization of food protein. The ratio of the first limiting amino acid of the measured food protein to the same essential amino acid in the reference protein is the amino acid score of the protein[9].

Table 3 lists the amino acid composition and amino acid scores of protein of some species of locusts. As can be seen from the table, locusts are rich in 17 amino acids and are complete proteins. The seven essential amino acids of the human body measured from them together account for more than 30% of the total amino acids. The limiting amino acid of locusts was calculated to be Met+Cys with an amino acid score of 0.412[8]. Therefore, the protein content of locusts is high and favourable for absorption. The amino acid composition of locusts meets the needs of human body, and the content of essential amino acids is the largest, which has rich nutritional value.

2.1.2 Prospects and limitations of locust protein

Currently, the exploitation of locust resources has achieved some results in the short term, but in general, the degree of utilization is still at a rudimentary level, and there is a lack of complete process design for locust products in various countries. In addition, the allergenicity of locusts needs to be taken into account, as cases of allergy to locusts have been reported in various countries. In this regard, it is necessary to carry out research on the toxicology of locusts to solve the corresponding problems[8]. In conclusion, locusts are rich in protein resources and have high exploitation value. It is believed that with the progress of science and technology, locust food can be further developed in terms of nutritional and health care functions.

2.2 Fats

2.2.1 Determination of fat content

Fat is an indispensable substance for the human body, which plays a role in energy reserves, maintaining body temperature, protecting internal organs, promoting vitamin absorption, synthesising hormones and so on. The human body needs fat to maintain normal physiological functions, but too much fat will cause harm to the body. For example, excessive intake of fat has become one of the triggers of obesity, hyperlipidaemia and many other diseases. For this reason, people are looking for alternatives to fat to prevent excessive fat intake[5].

Table 3 Fat content of different locust species (g/100g dry w t)[5,8,10]

species	Oedaleus infernalis Saussure	Acrida cinerea	Shirakiacris shirakii	Atractomorpha sinensis	Acrida exaltata Walker
Fat content (%)	9.00	8.42	9.05	8.53	7.07
species	Oedaleus decorus asiaticus	Chorthippus Fieber	Angaracris rhodopa	Oxya adentata Willemse	Oxya chinensis Thunberg
Fat content (%)	5.54	6.77	6.27	5.68	4.83
species	Spathosternum prasiniferum	Hieroglyphus banian Fabricius	Calliptamus abbreviatus	Locusta migratoria manilensis	
Fat content (%)	8.11	7.15	7.56	5.95	

Table 3 shows the fat content of several locust species determined by several experimental teams. The highest was the Shirakiacris shirakii with a fat content of 9.05 per cent. The lowest was the Oxya chinensis Thunberg with a fat content of 4.83 per cent.

2.2.2 Determination of fatty acid content

Table 4 The composition of Fatty acids of different locust species (g/100g dry matter)[5,8-10]

Locust species	Fatty acid composition (%)							
	14:0	16:0	16:1	18:0	18:1	18:2	18:3	UFA
Acrida cinerea	0.47	14.83	2.33	4.06	16.74	15.34	46.07	80.48
Atractomorpha sinensis	0.68	14.75	2.94	5.08	19.50	21.74	34.92	79.10
Shirakiacris shirakii	0.74	13.23	1.47	4.80	39.10	22.19	17.95	80.62
Oedaleus infernalis Saussure	0.67	8.63	2.93	3.08	34.36	19.17	30.50	87.00
Oedaleus decorus asiaticus	0.38	15.27	3.72	6.68	27.46	18.78	27.19	77.15
Chorthippus Fieber	0.48	15.35	4.05	7.45	26.62	16.26	30.27	77.23
Angaracris rhodopa	0.51	13.24	4.30	6.98	29.68	17.23	28.50	79.71
Chorthippus fallax	0.43	16.97	4.17	7.26	30.05	16.04	25.01	75.27
Locusta migratoria manilensis	2.06	17.52	3.74	9.77	17.56	14.83	29.66	67.86

Note: UFA is Unsaturated fatty acid.

As essential nutrients for human health, fatty acids play an important role in human metabolism. Among them, unsaturated fatty acids have the effect of regulating blood lipids, preventing blood clots and regulating immunity, thus playing a preventive role in atherosclerosis and cardiovascular diseases. Eating too much saturated fatty acids can easily cause cardiovascular diseases, most of the saturated fatty acid content of animal fats is high, while the body's essential unsaturated fatty acid content is relatively low.

Table 4 summarizes data from fatty acid measurements of locusts by several teams, from which it can be seen that locusts are rich in a wide range of fatty acid species and have a much higher content of unsaturated fatty acids than saturated fatty acids, with unsaturated fatty acids accounting for 67-87% of the total fatty acid content. Under the premise of low fat content, locusts are richer in unsaturated fatty acids than most animal nutrition sources. Therefore, locusts can be further developed and studied as a new low-fat food resource.

2.3 Vitamins

2.3.1 Determination of vitamin content

Table 5 Vitamin content of locusts and common foods (mg/kg)[10]

species	Vitamin B_1	Vitamin B_2	Vitamin E	Vitamin C	Carotene
Acrida cinerea	1.40	1.30			
Oxya chinensis Thunberg	0.42	16.20	33.18		5.10
Atractomorpha sinensis		0.51	1.52	3.22	0.50
egg	1.20	5.00	18.40		
pork liver	2.10	20.80		200	

Vitamins are a class of trace organic substances that maintain the normal physiological functions of living organisms and affect the growth, metabolism and development of the human body.Table 5 lists some of the measured vitamin content of locusts, from the table can be seen: different species of locusts rich in vitamins are also different, has been measured the presence of locusts in the body of B1 , B2 , E, C and carotene. Among them, the vitamin B1 content of Acrida cinerea is 1.40 mg/kg , which is close to the content in eggs. The Oxya chinensis Thunberg has the richer vitamin B2 content, reaching 16.20 mg/kg, which is close to the content of pork liver[10] .

2.3.2 Prospects and limitations of locust vitamins

Currently, the use value of locusts is mostly reflected in food and feeding, and the development of nutritional value is limited, so there is a lot of room for research on the detection and extraction of vitamins from locusts[11]. In order to meet the growing market demand, the development process should also be efficient and cost-saving. However, evidence from several studies shows that vitamins are not only present in large quantities in insects, but also play an important role in their growth and development. Vitamin deficiencies in higher animals have been well researched and solved, whereas in insects the research is still shallow.

2.4 Minerals

Mineral elements play an important role in the composition of animal tissues and in the maintenance of normal physiological activity, but excessive or insufficient intake of minerals can cause disease or lead to physiological abnormalities. Locusts can be a good source of mineral elements.Table 6 is the mineral element contents of different species of locusts measured by several experimental teams[7] , from the table, it is clear that locusts are very rich in Mg, Zn, Ca and Cu. In addition, trace elements such as Fe, Zn, Cu, Mn, Se, etc. were also detected in locusts.

Heavy metals were detected in all 12 locust species in the table. Taking elemental cadmium as an example, to calculate the minimum amount of fresh insects to be consumed, the FAO/WHO proposed a monthly tolerable intake (PTWI) of 25 μg/(kg·bw) for cadmium in 2010, and the per capita body weight of our country is calculated as 60 kg, which means the daily permissible intake is 1.5 mg. The maximum cadmium content of the test sample was 1.511 μg/g dry weight, and using this as a benchmark, about 993 g of these locusts would reach the limit. The maximum cadmium content of the test sample was 1.511 μg/g dry weight and on this basis, consumption of about 993g of these locusts would reach the limit. On this basis, moderate consumption of the insects is unlikely to result in heavy metal poisoning.

Table 6 Determination of mineral elements of different locust species (μg/g sample)[5-10]

Elemental content	Cr	Se	Mg	Cu	Al	Pb	Fe	Zn	As	Sn	Mn	Ca	Cd
Oxya chinensis Thunberg	29.3	2.44	1054	44.6	48.2	2.98	39.0	293	1.44	0.50	12.3	875	0.21
Calliptamus abbreviatus	17.8	6.20	1259	91.0	1026	6.34	399	247	4.62	1.56	11.4	2746	1.07
Atractomorpha sinensis	52.3	7.00	1585	49.7	237	6.52	176	308	7.10	1.94	12.2	1199	0.92
Acrida cinerea	26.9	6.53	975	49.4	109	11.4	103	297	3.27	1.63	8.40	927	0.68
Trilophidia annulata	64.2	8.70	1534	48.6	359	11.8	259	299	5.22	2.38	6.59	1142	0.74
Locusta migratoria manilensis	184	6.59	1334	50.4	321	4.09	182	381	7.61	2.21	9.89	675	0.63
Aiolopus tamulus	20.2	8.12	1409	52.5	327	4.83	196	351	4.97	2.09	0.17	731	0.59
Shirakiacris shirakii	50.2	6.66	1219	57.7	163	11.7	154	459	4.65	1.77	4.22	1126	1.51
Oedaleus infernalis $Saussur_e1$	17.5	7.17	1345	74.4	731	8.86	270	277	4.56	1.53	9.80	1209	0.56
Oedaleus infernalis $Saussur_e2$	28.8	7.47	663	55.0	99.5	6.77	102	359	4.18	2.28	12.8	913	0.58

Note: The samples of the Oedaleus infernalis $Saussure_1$ were taken from Inner Mongolia, China, and the samples of the Oedaleus infernalis $Saussure_2$ were taken from Xi'an, China.

3. Research on the biological functions of locusts

Locusts are not only rich in nutrients such as proteins, amino acids, oils, minerals and vitamins, but also have certain biological functions. Components such as superoxide dismutase (SOD) and bioactive peptides extracted from locusts have certain antioxidant and antibacterial effects[12]. Therefore, the positive effects of the biological functions of locusts on human health is also one of the important directions of the present insect research.

3.1 Efficacy of flavonoids

Flavonoids are a class of phenolic compounds with special physiological functions, mainly have the following biological roles[12,13]:

(1) Anti-cancer and anti-tumour effects. Flavonoids have the effect of clearing free radicals, directly inhibiting the growth of cancer cells and anti-cancer factors.

(2) Cardiovascular protection. Flavonoids have the effect of regulating lipid metabolism, through the regulation of lipid metabolism on the cardiovascular system to play a protective role in preventing and controlling coronary heart disease, hypertension and atherosclerosis.

(3) Anti-inflammatory and analgesic effects. Flavonoids have anti-inflammatory and analgesic effects, and can be used to treat clinical abscesses and ulcers as well as diseases caused by pathogenic microorganisms.

(4) Immunomodulatory effects. Flavonoids can be multiple cells, cytokines, as well as affect the thymus to carry out immunomodulatory effects, which can enhance the body's non-specific immune function and humoral immune function.

(5) Antibacterial and antiviral effects. Flavonoids antibacterial and antiviral effects have been confirmed by the pharmaceutical industry, such as ginkgo flavonoids, quercetin, and poplar flavonoids have antipathogenic microorganisms and antiviral effects.

(6) Antioxidant and anti-aging effects. Flavonoids have strong antioxidant effects, avoiding oxidative damage by inhibiting and scavenging free radicals and reactive oxygen species.

(7) Anti-radiation effects. Because of their anti-free radical effects, flavonoids have the ability to resist radiation.

3.2 Efficacy of superoxide dismutase

Superoxide dismutase (SOD) is widely distributed, it can scavenge the oxygen produced by cellular respiration and play the role of cell protection, so it has attracted great attention from domestic and foreign biochemical and pharmaceutical communities. McCord[14] determined the SOD content of a variety of microorganisms with different oxygen demand, and found that the existence of SOD is closely related to the aerobic metabolism of cells. At present, SOD has been isolated from bacteria, fungi, protozoa, algae, insects, fish, plants and mammals, etc. SOD is divided into three categories: Cu/Zn-SOD, Mn-SOD and Fe-SOD[5].

4. Conclusion

In recent years, the development of locust protein resources has received attention from various countries, but the overall level is still in the primary stage, especially the reports on locust food development are few, and locusts are still mostly consumed by primitive methods, and industrial production has not yet been carried out[15]. In addition, some people consume locusts are easy to cause allergy to heterogeneous proteins, suggesting that locust toxicological research should be accelerated to solve the problem of allergens as soon as possible[16]. For the development and utilization of locust protein resources, in addition to consolidating the development of traditional locust food, it is also necessary to accelerate the research and development of medical and health care products, to clarify the mechanism of its health care effects through the analysis of locust nutritional composition, and to develop influential health care food and medicines.

It is believed that locusts will become the most potential food resource[17] with the deepening of human understanding of health food and the nutritional value of locust protein resources. In the future, locust resources can be fully utilized to solve the problems of global food security and protein supply and contribute to the development of sustainable agriculture through the research and development of food processing, scale-up of farming, locust feed and medicinal value[18].

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