Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 43 (2009) 1236–1242
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Silkworms culture as a source of protein for humans in space

Yunan Yang [a], Liman Tang [a], Ling Tong [b], Hong Liu [b,*]

[a] Department of Environment Engineering, Beihang University, Beijing 100083, China
[b] School of Biological Science and Medical Engineering, Beihang University, Beijing 100083, China

Received 16 September 2006; received in revised form 11 December 2008; accepted 13 December 2008

Abstract

This paper focuses on the problem about a configuration with complete nutrition for humans in a Controlled Ecological Life Support System (CELSS) applied in the spacebases. The possibility of feeding silkworms to provide edible animal protein with high quality for taikonauts during long-term spaceflights and lunar-based missions was investigated from several aspects, including the nutrition structure of silkworms, feeding method, processing methods, feeding equipment, growing conditions and the influences on the space environmental condition changes caused by the silkworms. The originally inedible silk is also regarded as a protein source. A possible process of edible silk protein was brought forward in this paper. After being processed, the silk can be converted to edible protein for humans. The conclusion provides a promising approach to solving the protein supply problem for the taikonauts living in space during an extended exploration period.

Keywords: Controlled Ecological Life Support Systems (CELSS); Silkworm culture; Diet composition; Protein

1. Introduction

Life support has been a basic and critical issue since manned space flights were begun, especially for long-duration missions, such as the Space Lab aboard the space shuttles, the International Space Station and the lunar-base. Controlled Ecological Life Support Systems (CELSS), also called Bioregenerative Life Support Systems (BLSS), are considered to be the most advanced Life Support Systems now. This system, in which the internal mass and energy exchange go on in a closed manner, continuously provides taikonauts with life necessities such as oxygen, water and food. Except for sunlight, such a system is highly regenerative. It requires minimum resupply and establishes a stable dynamic equilibrium inside ecological environment to make sure well being of the crew members. CELSS are also the most complicated systems, providing permanently regenerative resources and making long-term space flights and space explorations more adaptable and safer. Compared with other life support systems, CELSS costs less and is more suitable for long-term manned space flights exceeding 3 years. The development and maturity of CELSS mainly depend on the closed system improvement including reliability, closure degree and so on.

The taikonauts' diets influence the CELSS composition and structure. In recent years, extensive researches have been carried out on this issue by USA, Russia, Japan, and Europe (Barstev et al., 1996; Drysdale et al., 2002; Ashida, 2003; Czupalla et al., 2005). Studies on the requirements towards space animals feeding to provide edible animal protein have been conducted (Manukovsky et al., 2005; Czupalla et al., 2004). The National Aeronautics and Space Administration (NASA) explored in space growth systems of higher plants including wheat, soybean and potatoes. These plants on earth utilize sunlight to grow and produce edible amylum, protein and vitamins. Besides, they also resorted to breeding fish to supply animal protein to make sure there were comprehensive and ample nutrients in the astronauts' diets. Besides, researches all over the world investigating fish and amphibian have achieved much progress. The selected fish species included

* Corresponding author.
E-mail address: LH64@buaa.edu.cn (H. Liu).

0273-1177/$36.00 © 2008 COSPAR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.asr.2008.12.009

Xiphophorus helleri (Blüm et al., 1995a; Gitelson et al., 1995), *rainbow trout* (Uchida et al., 2002), *Tilapia* (Blüm et al., 1995b), *Xiphophorus helleri* (Bluem and Paris, 2003), *Oryzias latipes* (Shimura et al., 2002), *Crenopharyngodon Idellus* (Gitelson et al., 1995), etc. In addition, some European countries and Japan have studied the *urchin larvae* (Brinckmann and Schiller, 2002), snail *Iomphalaria Glabrata* Bluem and Paris, 2003 and *Cynops pyrrhogaster* (Mogami et al., 1996; Shimura et al., 2002). However, fish and amphibians are sensitive to the water conditions. For example, the effects of accumulated nitrate in water may cause a delay in spawning, hatching and development of these animals (Shimura et al., 2002). Besides, researches on poultry feeding have been popular. But raising poultry requires relatively large space, large amounts of feedstuff, and produces many metabolic wastes to treat in the system, causing the problem of big expenditure. Insect breeding in space was first proposed by Robert Kok in 1983. America company HOTLIX® is the original edible insect candy creator. For the past 20 years, HOTLIX® has been making people delighted with their outrageous confections featuring real insects including worm, cricket, scorpion, ant, butterfly and so on embedded inside the candies (http://www.hotlix.com). Russia has also explored approaches that use inesculent portions of space crops as a soil-like substrate to feed California worms and grow mushrooms with the original aim to process the inedible parts of crops such as wheat straw and so on (Tikhomirov et al., 2003). However, the California worms were not easily accepted as animal protein by the Russian astronauts. How to make use of limited space and other conditions to produce animal protein appropriately for the taikonauts is a vital problem to solve in CELSS.

Diet structure mainly depends on different diet preferences of different nations. The silkworm, including mulberry silkworm and non-mulberry silkworm pupae, has been a favorite Chinese food from ancient time. Silkworm living on mulberry (*Bombyx mori*) leaves has the following merits: high protein content, reasonable nutrient compositions and ample contents, a short lifespan, easy breeding method, small growth room, and little odor and wastewater produced. This paper carries out investigations on the aspects of silkworm nutrition structure, food processing, feeding equipments, and the feeding influences on the taikonauts' living environment. Finally, we discuss the feasibility of silkworm culture to produce edible animal protein in CELSS. We hope that this can provide a possible approach to meeting the animal protein requirement of the crew in CELSS.

2. Chinese silkworm consumption tradition

Silkworm consumption has a long history in China. Silkworms have been used as animal fodder, food and medicine by Chinese for a long period of time. Records of silkworm consumption could be found in the book "Qi Min Yao Shu" written 3000 years ago (Zhang and Zhang, 2001). The silkworms eating habit is very popular in China, people in Shandong province and northeast China like eating silkworm pupae, whereas Henan province and the people in southern China consume the silkworm moths. In Yunnan province, people have formed a quite distinctive diet culture of eating insects (Yang, 1999). Recently, Chinese have developed more applications of silkworm protein, not only using silkworm, pupae and moths as food, but also utilizing them to realize some hygienic and medical functions.

3. Mulberry silkworm pupae nutrition evaluations and the edible values of silkworm larva

Silkworm pupa is the main part of the cocoon, equalling 80% of the weight of the fresh cocoon and 50% of the dry cocoon. The pupae protein of yellow blood silkworm (a subspecies of *B. mori*) could be over 60% of the dry weight (Wu, 2001). As we know, a large egg provides 6 g of protein, Average weight of *B. mori* pupae is 0.09 g. For each kilogram of body weight a human needs to consume 1 g of protein every day. For example if a person's body weight is 60 kg, he must consume 60 g of protein per day. Assuming normal intake protein ratio of plant protein to animal protein is 3:1 daily, the number of silkworm pupae and cocoons consumed per person per day based on the nutritional requirements is 170 per person per day. Table 1 shows the amino acid scores of silkworm pupa (WHO, 2007; Zhang et al., 2000). One piece of silkworm pupa contains 18 kinds of amino acids, and 8 of them are essential amino acids for human beings (14.59% of total protein and 40% of total amino acids (Qian, 1997). The human body needs eight kinds of human essential amino acids absorbed from food which are Ile, Leu, Lys, Met, Phe, Thr, Val, Trp, their contents in silkworms are two times higher than those of pork and four times than those of egg and milk. Pupae protein is a complete protein and the amino acids compositions are with appropriate proportions in line with FAO/WHO standards (Xia and Zhao, 2003; Chen et al., 2002a,b). Besides, silkworm pupae has

Table 1
The indispensible amino acids scores of silkworm pupa.

Indispensible amino acids	Amino acid score
Histidine	0.64
Isoleucine	0.74
Leucine	0.51
Lysine	0.56
Methionine	0.63
cystine	0.7
Methionine + cysteine	–[a]
Phenylalanine + Tyrosine	1.1
Threonine	0.72
Tryptophane	1.1
Valin	0.57

[a] Cysteine can be translated from methionine and can transform to the cystine which can also transform to cysteine, therefore the cysteine content depends on these two reactions.

abundant fatty acid (mainly unsaturated fatty acid) (Qian, 1997)(Table 2), chitin, vitamins A, D, B_1, B_2, B_5, microelements, antibiosis peptides, hormones, lysozym, rgosterin, etc. (Xiong and Chen, 1999). After only a month's growth, the mulberry silkworm enters the stages of pupation. The unsaturated fatty acid in the silkworm pupae fat could reach approximately 30%, 8%–10% of which is non-esterified fatty acid. More than 30% of pupae oil is linolenic acid which is the raw material of human DHA exerting an important effect on human intellect and memory improvement, sight-protection and is a precaution chemical against hyperlipoidemia (Lu et al., 1998). Moreover, some unsaponifiable ingredients, including β-sterol, cholesterol and campesterol, make up approximately 1% of silkworm pupae fat. Silkworm pupae is an extraordinarily valuable edible animal protein resource.

Silkworm culture costs a short time, only 25 days or so. There are five instars during the silkworm larval phase. After freezing desiccation, and porphyrization, silkworm larvae on the third day of the fifth instar can be processed to be silkworm powder. This powder contains 4%–5% water, 60% protein, 9%–13% fat and 6%–7% cellulose. The contents of protein, fat and trace elements are higher than those of mulberry, but the cellulose and lignine content are much lower (Gui and Zhuang, 2000) than the latter one. Silkworm powder can be easily digested and absorbed by human bodies. It also can promote the physiological functions of the gastrointestinal tract. Furthermore, silkworm powder plays an excellent role in lowering blood-glucose levels. Since first reported by Korean scholar K.S. Ryu (Ryu et al., 1997), extensive researches were carried out in China (Xiao et al., 2005; Gui et al., 2001). The results of animal feeding experiments showed that silkworm powder could decrease blood-glucose contents rapidly with no negative effects. Long-term consumption can improve immunity and does not cause glycopenia. Because of these reasons, silkworm powder may be considered as one of animal protein sources with high quality for taikonauts.

4. The nutritional values and food processing method of Silkworm silk

The silkworm silk fiber contains more than 98% protein. It is composed of two-strip fibroins and covered by sericin (Feng, 2004). Fibroins are crystal fabric protein and compose the main portion of the cocoon. They contain 18 kinds of amino acids, about 7% of which are eight essential human amino acids whose contents in silk fiber are less than those in pupae. The intermediate product by hydrolyzation of sericin is silk peptide. The amino acid compositions of silk peptide are similar to fibroin, mainly composed of Gly, Ala, Ser, and Try. These four kinds of amino acids can reach 88.4% in the silk peptide's total amino acids. Sericin, a kind of highly hydrophilic protein, acts as an adhesive in the silkworm cocoon (Teramoto et al., 2004). Its component is sericin protein which occupies 25% of the cocoon weight. Sericin contains 18 kinds of amino acids, of which over 90% can be easily absorbed by human bodies, over 17% of which are eight kinds of essential amino acids. This value is higher than that in common food (Zhang et al., 2000).

One approach to hydrolyzing silk is called the Ajisawa method (Ajisawa, 1998). After boiled off, the silk is added into the mixed solution with the proportion of one part silk to 15 parts Ajisawa reagents in terms of weight (mass ratio of calcium chloride, ethanol, water is 111:92:144), and then heated to 75 °C. After hydrolyzed, the silk is dissolved in the solution forming a limpid silk protein solution. After purification and disinfection, the solution becomes a colorless, tasteless and odorless edible fibroin powder. Then this powder is mixed with suitable seasoners like fruit juice, sugar, a pigment, flavoring and citric acid and converted into a colloidal substance (edible fibroin) at the temperature below that of the room. The colloid can dissolve immediately in the mouth and is tasted like a lubricating jam similar to the taste of the jelly sold in the market. The silkworm silk's edible value mainly depends on its nutritional values and the amounts digested and absorbed by humans (Yamada et al., 2001). The experiment results proved that the edible fibroin could be digested normally by humans. Moreover, it could promote the absorptions of some elements such as Zn, Fe, Mg, and Ca in the human intestine (Sasaki et al., 2000). It was also found that the edible fibroin could resist multienzyme degradation, similar to buckwheat protein. Used as a food additive, fibroin could improve human health (Kato et al., 2000). A mice feeding experiment showed 90% amino acids of fibroin could be digested by animals. It also reduced the mice's high cholesterol levels (Zhang, 1995).

Table 2
The free fatty acid of the silkworm pupae oil (Qian, 1997).

Substance	Content (%W′/proteinW)
Teradecyl acid	0.380
Octadecanoic acid	7.110
Hexadeeene acid	0.490
Hexadecanoic acid	20.90
Linolic acid	7.470
Linolenic acid	30.50
Oleinic acid	33.10

5. Feasibility of the silkworm culture in space

The scenario of silkworm culture to provide taikonauts with edible animal protein during the space missions utilizing the unfavorable parts of vegetables as the silkworm food (Fig. 1). Silkworm culture in space provides animal protein source with a high quality for taikonauts during the space missions. Meanwhile, space plants not only provide taikonauts with plant protein and other nutrients, but also supply silkworm with the leaves of vegetables as foodstuff, for example, lettuce leaves. Wastes produced by silkworms as well as taikonauts, can be utilized by plants as fertilizers.

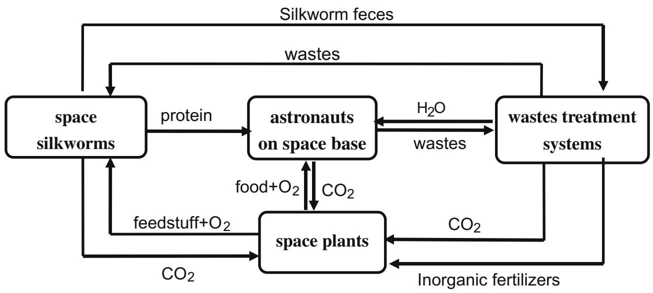

Fig. 1. The scenario of silkworm culture to provide taikonauts with edible animal protein.

5.1. Utilization of vegetables leaves as the silkworms' food

To solve the problems of the silkworms' foodstuff, it is possible to use the unfavorable parts of vegetables such as leaves to feed the silkworms. Space planting of leaf vegetables already shows unprecedented progresses. In the early 1990s, vegetable cultivation experiments were successfully carried out aboard the MIR space station (Ivanova et al., 1998). Recently the researches on the hydroponic culture of vegetables have also entered the practical stage (Moraru et al., 2004). The research achievements of growing leaf vegetables in space demonstrate the possibility of feeding silkworms. However, the monotonic vegetative (mulberry leaf) food structure of the silkworm is still a problem. Japan has already cultivated euryphagous silkworms (Kanda, 1987). The food candidates for these silkworms are more extensive. In recent years China has also conducted studies focusing on the euryphagous silkworms. According to Xu(Xu, 1994), using lettuce and cabbage leaves to raise ten kinds of silkworms, experimental results confirmed that these silkworms could ingest the leaves and grow.

5.2. The feasibility of silkworms culture in the space environment

The CELSS environment is essential for the taikonauts living in the outer space to realize the food necessities self-supplied when the habitation period exceeds 3 years. Bartsev proposed the view that the optimized CELSS had characteristics associating with the most convenient, the securest and the most satisfactory qualities of life (Barstev et al., 1997). Successful silkworm culture in space should also consider the influences of the radioactive rays and microgravity in deep space that exert effects on the silkworm developments. Appropriate feeding facilities and conditions should also be explored in order to assure that the silkworm can adapt to the space environment easily. All of these demand more advanced equipments and conditions than the existing ones now.

In order to feed animals in space, Germany affiliated with ESA developed several animal feeding systems. For example, the "Closed Equilibrated Biological Aquatic System" (CEBAS) is primarily developed for the aquatic animals. This system can maintain dissolved oxygen (DO) in the water at a level of not less than 3.5 mg/L with the water temperature sustained at 25 °C. It contains an advanced filter and video monitor equipment (Blüm et al., 1995a). A device used to raise the small mammal animals under the microgravity condition is also being developed by Russia, but it is still in the experimental stage (Gitelson et al., 1995). One cultivating device invented by CSA mainly focuses on insect cultivations. This device is composed of six small insect incubators and an outside microgravity cabin. It can control temperature ranging from 15 °C to 30 °C, air relative humidity changing in the range of 40%–80%, illumination between 0 and 20 $\mu W\ cm^{-2}$ with a broadband light source. This device has a monitoring system which can monitor the air exchange and CO_2/O_2 concentrations, vibration and radiation. It has been already successfully used as a breeding experiment in the space flights. The comprehensive animal incubator developed by International Space Station (ISS) has various functions to cultivate several kinds of animal species including mammals, amphibians, microorganisms and insects. The temperature in the specimen chamber of this incubator can be controlled in the range of 4–45 °C. The air is recirculated at a rate of approximately 50 mL/min. Variable gravity levels can be set for different experiments and it has an advanced monitoring system (Kerm et al., 2001). These systems provide a facility guaranteeing the silkworm culture in space with appropriate technical supports.

Adequate room is vital to space animal feeding. It is necessary to provide appropriate area to feed the animals. The study showed that in the restricted space, animal growth and metabolism declined; the efficiency of converting foodstuff to animal protein was also lowered, consequently leading to yield reduction (Sibbald et al., 2000). Therefore, selecting animal species that can utilize the limited space to produce protein should be a vital principle. Room limitation influences poultry feeding in terms of yield and quality, for example, according to data in the goat raising on the ground, the required room for feeding one goat is over 10 m^3 (Wang, 2003). An approach to solving this problem still needs to be found. The individual silkworm is small, this feature makes the restricted space base effectively utilized. Studies showed that silkworm growing density mostly depended on the food distribution. It could reach a high density in the silkworm feeding industry (Zhu and Xie, 2001). The calculated feeding room is less than 2 m^3 for seven persons. Therefore a smaller required space is the advantage of silkworm culture.

5.3. The potential effects on the space environment caused by the silkworm culture

Environment control and the life support system of the space cabin are essential in the manned spacecraft and the space bases. It ensures the taikonauts to lead a normally active life, In order to achieve a harmonious coexisting between humans and animals in the same space environment, it is necessary to consider the possible influences of the space silkworm culture on the whole CELSS. There are several effects caused by silkworm culture that should be taken into account:

5.3.1. Effects on the atmospheric control system

The atmospheric control system mainly include the cabin pressure-control system, the CO_2 collection, oxygen regeneration system, and the ventilation system. The silkworm culture will produce some waste gas composed of CO_2, ammonia and other minor gas pollutants such as SO_2 (Yu, 2004) and so on. The filtration device in the silkworm culture equipment purifies and dries the waste gases. Removal of the gas pollutants with small quantity mainly depends on the catalysis oxidation technique in the gas filtration system. After purification, the main component of the mixed gas is CO_2 and it can be effectively absorbed and translated into oxygen via the advanced CO_2 enrichment and collection system (Satyapal et al., 2001). So the waste gases produced during the space silkworm culture is purified and then directly released into the silkworm culture cabin.

5.3.2. Effects on the water control system

The space cabin water control system includes a water circulation and regeneration system, a wastewater treatment system and a water stabilization system (Huang and Shen, 2000). The utility principal of water is to keep the air relative humidity in the culture cabin constant. Silkworm does not need to live on water with little wastewater produced, because between the 5th instar and the pupal stage the silkworm excretes a small amount of urine, $0.2 \sim 0.5$ ml per moth. The pH value of urine is approximately $5.8 \sim 6.3$. Moth urine mainly contains uric acid and urea. In uric acid N content is 76.4% with 23.6% of N existing in urea (Wang, 2004). So only about 1 L of wastewater needs to be treated.

5.3.3. Effects on the food and waste management systems

Space silkworm culture depend on artificial food or the unfavorable parts of the space cultivated vegetables. Based on CELSS principles, using the latter one is more appropriate (Drysdale et al., 2002). Space silkworm culture possesses more space requirements if vegetables are used, but it can also provide considerable edible animal protein for taikonauts. The silkworm is a phytophagous insect, it is easy to decompose its metabolites. Furthermore, potentially the taikonauts could utilize them as fertilizer for the space plants (Yang et al., 2002). Human, animal and plant waste products must be recycled in CELSS. In this study, we will select composting under high temperature as a solid wastes treatment method, the compost is mainly the silkworm excretea and the inedible part of plants.

Based on the above three points, space silkworm culture will not have adverse effects on the space cabin environment.

5.4. Effects of the silkworm protein on human health

The silkworm contains abundant protein and various kinds of amino acids, fatty acids, linolenic acid and mineral substances. These nutrient elements can meet the needs of human being towards physical fitness. Chinese have used silkworms as food for thousands of years. Negative effects on human health have not been reported yet. Silkworm protein has many health protecting functions. It has been proven that silkworm protein has a curative effect in curing diabetes. A clinical experiment showed that the blood-glucose content of a patient declined by 20% after four weeks of treatment using silkworm protein (Ryu et al., 1997). Chitin separated from the epidermis in the silkworm pupae has specific functions in health protection and cancer resistance (Hu et al., 2005). These functions are of great importance to taikonauts in the space full of cosmic radiations. So the silkworm protein can provide taikonauts with adequate animal protein, maintain and promote human health.

6. Conclusion

Diet problems during extended residence in space, especially animal protein supply, are the key issues in CELSS. Because the silkworm contains high-quality protein and essential nutrient elements for human, it has already been considered as an important diet component in many regions of China. The studies in this paper show that silkworm food has many positive characteristics, such as high protein content, appropriate proportions of the amino acids and unsaturated fatty acids that conform to human nutrition requirements. Silkworms will promote human health. Silkworm culture requires shorter time and less growing room than other animal species. Therefore the silkworm is a good space animal candidate. Space biology techniques can facilitate the space silkworm culture. The developments of the space animals incubation devices enable the long-term silkworm culture. The space silkworm culture can provide an easily implemented approach to producing animal protein for taikonauts during the long-term space missions.

Acknowledgement

This research was sponsored by the Ministry of Science and Technology of China Grant (2006DFB81140).

References

Ashida, A. Considerations of design for life support systems. Adv. Space Res. 31 (7), 1805–1809, 2003.

Ajisawa, A. Dissolution of silk fibroin with calciumchloride/ethanol aqueous solution[J]. J. Sericulture Sci. Jpn. 67 (2), 91–94, 1998.

Barstev, S.I., Mezhevikin, V.V., Okhonin, V.A. BIOS-4 as an embodiment of CELSS development conception. Adv. Space Res. 18 (1/2), 201–204, 1996.

Barstev, S.I., Gitelson, J.I., Lisovsky, G.M., Mezhevikin, V.V., Okhonin, V.A. Perspectives of different type biological life support systems (BLSS) usage in space missions. Acta Astronaut. 39, 617–622, 1997.

Bluem, V., Paris, F. Possible applications of aquatic bioregenerative life support modules for food production in a Martian base. Adv. Space Res. 33, 77–86, 2003.

Blüm, V., Andriske, M., Kreuzberg, K., Schreibman, M.P. Animal protein production modules in biological life support systems: noval combined aquaculture techniques based on the closed equilibrated biological aquatic system (CEBAS). Acta Astronaut. 36, 615–623, 1995a.

Blüm, V., Andriske, M., Eichhorn, H., Kreuzberg, K., Schreibman, M.P. A Controlled Aquatic Ecological Life Support System (CAELSS) for combined production of fish and higher plant biomass suitable for integration into a lunar or planetary base. Acta Astronaut. 37, 361–371, 1995b.

Brinckmann, E., Schiller, P. Experiments with small animals in BIOLAB and EMCS on the international space station. Adv. Space Res. 30, 809–814, 2002.

Chen, Z., Liao, S., Li, Q., Chen, L., Wu, Y., Yao, X. Study on multivoltine yellow blood silkworm for edible and medicine utilization. Silkworm Sci. 28, 73–76 (in Chinese), 2002a.

Chen, Y.G., Zi, M., Hai, L.N., Zhang, Y. Analysis of amino acids from silkworm chrysalis. Yunnan Chem. Technol. 6, 22–23 (in Chinese), 2002b.

Czupalla, M., Aponteb, V., Chappellb, S., Klaus, D. Analysis of a spacecraft life support system for a Mars mission. Acta Astronaut. 55, 537–547, 2004.

Czupalla, M., Horneck, G., Blome, H.J. The conceptual design of a hybrid life support system based on the evaluation and comparison of terrestrial testbeds. Adv. Space Res. 35, 1609–1620, 2005.

Drysdale, A.E., Ewert, M.K., Hanford, A.J. Life support approaches for mars missions. Adv. Space Res. 31, 51–61, 2002.

Feng, P. The study of structure and edibility of silk protein. Food Res. Dev. 25, 51–54 (in Chinese), 2004.

Gitelson, J.I., Blüm, V., Grigoriev, A.I., Lisovsky, G.M., Manukovsky, N.S., Sinyak, Y.E., Ushakova, S.A. Biological–physical–chemical aspects of a human life support system for a lunar base. Acta Astronaut. 37, 385–394, 1995.

Gui, Z., Zhuang, D. Study on the silkworm powder and its physiological functions. China Sericulture 2, 53–54 (in Chinese), 2000.

Gui, Z., Chen, J., Chen, W., Zhuang, D. Effect of silkworm powder (SP) lowering blood-glucose levels in mice and its mechanism. Sci. Sericulture 27, 114–119 (in Chinese), 2001.

Hu, D., Liu, Q., Cui, H., Wang, H., Han, D., Xu, H. Effects of amino acids from selenium-rich silkworm pupas on human hepatoma cells. Life Sci. 77, 2098–2110, 2005.

Huang, Z., Shen, X. Space station environment control and life support. Aerospace China 2, 28–32 (in Chinese), 2000.

Ivanova, T.N., Kostov, P.T., Sapunova, S.M., Dandolov, I.W. Six-month space greenhouse experiments – a step to creation of future biological life support systems. Acta Astronaut. 42, 11–23, 1998.

Kanda, T. The silkworms' eating selecting characteristics and the success cultivation of *Euryphagous* species[J]. Silk Technol. (134), 28–35, 1987.

Kato, N., Kayashita, J., Sasaki, M. Physiological functions of buckwheat protein and sericin as resistant proteins. J. Jpn. Soc. Food Sci. 53, 71–75, 2000.

Kerm, V.D., Bhattacharya, S., Bowman, R.N., Donovan, F.M., Ellan, C., Fahlen, T.F., Girten, B., Kirvenbrooks, M., Lagel, K., Meeker, G.B., Santos, O. Life sciences fight hardware development for the international space station. Adv. Space Res. 27, 1023–1030, 2001.

Lu, P., Lai, B.S., Yan, X.L. Purification and determination of α-Linolenic acid in silkworm pupa by urea adduction fractionation method. Chin. J. Pharma. Anal. 18 (6), 390–393 (in Chinese), 1998.

Manukovsky, N.S., Kovalev, V.S., Somova, L.A., Gurevich, Yu.L., Sadovsky, M.G. Material balance and diet in bioregenerative life support systems: connection with coefficient of closure. Adv. Space Res. 35, 1563–1569, 2005.

Mogami, Y., Imamizo, M., Yamashita, M., Kurotani, I.A., Wiederhold, M.L., Koike, H., Asashima, M. Astronew-early development of newt in space. Adv. Space Res. 17 (6/7), 257–263, 1996.

Moraru, C., Logendra, L., Lee, T., Janes, H. Characteristics of 10 processing tomato cultivars grown hydroponically for the NASA advanced life support (ALS) program. J. Food Compos. Anal. 17, 141–154, 2004.

Protein and Amino Acid Requirements in Human Nutrition. WHO Technical Report Series 935 (2007).

Qian, J. The chemical constitution and utilization of silkworm pupae. Sci. Technol. Food Industry 5, 42–43 (in Chinese), 1997.

Robert, K. The production of insects for human food. Can. Inst. Food Sci. Technol. J. 16 (1), 005–018, 1983.

Ryu, K.S., Lee, H.S., Choue, R.W. An activity of lowering blood-glucose levels according to preparative condition of silkworm power. Koeran J. Sericulture Sci. 39, 79–85, 1997.

Sasaki, M., Yamada, H., Kato, N. Consumption of silk protein, sericin elevates intestinal absorption of zinc, iron, magnesium and calcium in rats. Nutr. Res. 20, 1505–1511, 2000.

Satyapal, S., Filburn, T., Trela, J., Strange, J. Performance and properties of a solid amine sorbent for carbon dioxide removal in space life support applications. Energy Fuels 15, 250–255, 2001.

Shimura, R., Ijiri, K., Mizuno, R., Nagaoka, S. Aquatic animal research in space station and its issues-focus on support technology on nitrate toxicity. Adv. Space Res. 30, 803–808, 2002.

Sibbald, A.M., Shellard, L.J., Smart, T.S. Effects of space allowance on the grazing behaviour and spacing of sheep. Appl. Ani. Behav. Sci. 70, 49–62, 2000.

Teramoto, H., Nakajima, K., Takabayashi, C. Chemical modification of silk sericin in lithium chloride/dimethyl sulfoxide solvent with 4-cyanophenyl isocyanate. Biomacromolecules 5, 1392–1398, 2004.

Tikhomirov, A.A., Ushakova, S.A., Manukovsky, N.S., Lisovsky, G.M., Kudenko, Y.A., Kovalev, V.S., Gubanov, V.G., Barkhatov, Y.V., Gribovskaya, I.V., Zolotukhin, I.G., Gros, J.B., Lasseur, C. Mass exchange in an experimental new-generation life support system model based on biological regeneration of environment. Adv. Space Res. 31, 1711–1720, 2003.

Uchida, S., Masukawa, M., Kamigaichi, S. NASDA aquatic animal experiment facilities for space shuttle and ISS. Adv. Space Res. 30, 797–802, 2002.

Wang, W.Z.H. Management of mature silkworm mounting. Shanxi Agriculture 04, 41–42 (in Chinese), 2004.

Wang, Z.Q. Culture method of goats in suburb of Fujian. Fujian J. Ani. Husbandry Vet. 2, 34 (in Chinese), 2003.

Wu, Y.M. Study on nutrient ingredients of yellow blood silkworm. Guangdong Agric. Sci. 04, 31–33 (in Chinese), 2001.

Xia, W., Zhao, D. The chrysalis of silkworm synthesizes to develop the present condition and technique. J. Shaanxi Normal Univ. (Natural Science Edition) 31, 265–269 (in Chinese), 2003.

Xiao, H., Si, X., Luo, C., Cui, W., Li, R. Comparative study of silkworm powder compound on lowering both blood glucose level and blood fat level. Sci. Sericulture 31, 171–174 (in Chinese), 2005.

Xiong, Y., Chen, H. The comprehensive utilization of silkworm chrysalis. Nat. Prod. Res. Dev. 11, 82–85 (in Chinese), 1999.

Xu, H. The experiments on the silkworms food habit. Newslett. Sericulture Tea 3, 1–4 (in Chinese), 1994.

Yamada, H., Nakao, H., Takasu, Y., Tsubouchi, K. Preparation of undegraded native molecular fibroin solution from silkworm cocoons. Mater. Sci. Eng. 14, 41–46, 2001.

Yang, D. Study on the edible insects resources and insects food culture of Yunnan province. Entomol. Knowledge 36, 122–125 (in Chinese), 1999.

Yang, H.X., Zhu, X.R., Fang, Z.M. Research progress of the exploitation and utilization of the silkworm's excreation. Bull. Sericulture 3, 9–13 (in chinese), 2002.

Yu, Y. Why should accommodate the atmosphere of silkworm culture room. Guangxi Sericulture 41, 49 (in Chinese), 2004.

Zhang, F., Zhang, Z. Study on edible insect resources and their exploitation and utilization. Resour. Sci. 23, 21–23 (in Chinese), 2001.

Zhang, M., Haga, A., Sekiguchi, H., Hirano, S. Structure of insect chitin isolated from beetle larva cuticle and silkworm (*Bombyx mori*) pupa exuvia. Int. J. Biol. Macromol. 27, 99–105, 2000.

Zhang, Y. Study on new approach of silk fibroin utilization. Chin. Bull. Entomol. 32, 254–255 (in Chinese), 1995.

Zhu, J., Xie, D. Studies on standard techniques of rearing male silkworm hybrid 2: the influence of different rearing density and the amount of leaves for culture on the output of cocoon during young larva stage. Bull. Sericulture 33, 13–16 (in Chinese), 2001.