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Review Paper / Derleme Makale

Dairy Products in Space Nutrition and Potential Processing of Dairy Products with 3D/4D Printers as a Space Food

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ABSTRACT

Dairy products, which have been used for many years in the nutrition of individuals, have many benefits for human health. Due to recent developments such as climate changes, raw material deficiency and increased population, humankind has been forced to seek alternative resources from the space in the latest decades. Yet, in the space, feeding has for so long been world-centered and effectuated short term. Due to swift rise of 3-dimensional and 4-dimensional printer technologies at the end of 20th century, onset of 21st century, quick expansion, and wide use of such technologies, their use in space missions and space-food production has come to the surface. Within the context of this study, data related to utilizing dairy products as a space food and data on using 3-dimensional (3D) and 4-dimensional (4D) printers to generate these products in space mission were collected and evaluated in the review.

Keywords: Space Food, Dairy Products, 3D Printer, 4D Printer, Novel food processing

Uzayda Beslenmede Süt Ürünleri ve 3D/4D Yazıcılarla Üretilecek Süt Ürünlerinin Uzay Gıdası Olarak Kullanım Olanakları

ÖZ

Bireylerin beslenmesinde çok uzun yıllar boyunca kullanılan süt ürünlerinin insan sağlığı açısından birçok faydası bulunmaktadır. İnsanlığın son yıllarda gerek iklim krizi, gerek hammadde yetersizliği gerekse de artan nüfus etkisi ile farklı kaynakları uzaydan arama çalışması hız kazanmıştır. Uzayda beslenme ise; uzun yıllar boyunca dünya kaynaklı ve kısa süreli olarak gerçekleştirilmiştir. 3 boyutlu ve 4 boyutlu yazıcı teknolojilerinin 20. yüzyılın sonu ve 21. yüzyılın başında ortaya çıkması ve hızlı bir şekilde yayılıp, geniş kullanım alanı bulması sebebiyle uzay görevlerinde ve uzay gıdaları üretiminde de kullanımı söz konusu olmuştur. Bu çalışma kapsamında, uzay gıdası olarak süt ürünlerinin değerlendirilmesi, 3 boyutlu (3D) ve 4 boyutlu (4D) yazıcıların bu ürünlerin uzay görevi sırasında üretilmesi için kullanılması konusunda bilgiler derlenmiş ve değerlendirmeler yapılmıştır.

Anahtar Kelimeler: Uzay gıdası, Süt ürünleri, 3 boyutlu yazıcı, 4 boyutlu yazıcı, Yenilikçi gıda işlemesi

INTRODUCTION

Throughout history one of the greatest wonders of humanity has been cosmos and sky objects. That is the exact point that researches of many civilizations focused on and in result of these researches, a good number of scientific discoveries have also blossomed. In 1957 launching of the first artificial satellite Sputnik by Russia became a major turning point for humanity and humanity thus began to explore the space by the tools it generated and gained novel insights from this exploration [1]. Since the start of 1960, significant developments have been achieved in space flight technologies. Such developments helped to extend the time spent in the space from minutes to days first, then from months to years as can be seen in our age [2]. In the post 2nd World War, preparation of NASA for space mission and ground steps Soviet Union took in this attempt accelerated the researches about living and trading in space and as expected, humanity began to wonder if ‘’life in space is possible’’. That perspective gave rise to develop varied foods for astronauts and cosmonauts on a long- term space mission. Since the 108-minute flight of Yuri Gagarin in 1961 they have been eating food in space. With the advent of 1961 both the USA and Russia conducted researches to develop safe, instantly-made, instantly-consumed, compact and packaged foods with minimum waste while also appealing and nutritious to be consumed in space. Humanity's products in their space adventure consist of foods that were already widely consumed by astronauts and cosmonauts and reflect traditional traces from their diet on earth [3]. Besides the most vital issue in that matter is to provide the ingredients that humans at space mission need and prepare foods by taking space conditions into account. Milk, by virtue of many ingredients in its composition, is a food type with high digestibility. At the same time it is a vital resource for the items that must be taken on a daily basis. Carbohydrate group corresponds to around 30% of the dry matter of milk and cow milk that refers to most of the drinking milk. Main carbohydrate of milk is a form of disaccharide; lactose. Milk fats contain specific fatty acids with saturated and unsaturated traits; furthermore it plays active role in dissolving some of the vitamins contained in milk. Building and repairing effect of milk proteins for nutrition and muscle growth (adequate ratios of essential amino acids) is also an emphasis on the value of milk in terms of essential nutrients [4, 5]. Fermented milk constitutes another group and can be categorized as a microorganism source with probiotic features. Hence milk and milk products provide great health benefits and offer substantial benefit in human nutrition [6]. In modern age, consumption habits shifted towards fast consumption and production periods shortened. In parallel with these objectives exponential transformations also took place in production stages. In that aspect, inclusion and integration of 3-dimensional printers to production process and inclusion of 4-dimensional printers to this process too in near history came to the surface. As a consequence of evolution of space mission into life in space, the possibility of producing in stages our traditional and popular foods - milk and dairy products- in space territory has been examined within the scope of this study.

SPACE ADVENTURE OF HUMANITY AND FOOD CONSUMPTION IN SPACE

Space journey that first began as Russia launched to space Sputnik satellite and first living being to space [7] continues full speed in present age and it is envisaged that in the 21st century, a tiny colony will be set up in the planet and first steps to a new life will thus be taken. Initiated by Soviet Russia before the appearance of space programs led by the USA in 1961, space adventure of humanity has gained further impetus. First consumption of food, however, took place in 1961 in space [8]. In space adventure USA alone managed to take huge steps at certain intervals and particularly with the initiatives of International Space Station (ISS) an extensive research process uniting researchers from entire world started. In the advancement of space researches early steps taken by Soviet Russia and modern Russian cosmonauts and researchers contributed immensely to building the process as it is now. It is witnessed that certain space programs in particular hold up a critical position in the space adventure of humankind. Within the context of this analysis, programs developed by NASA have been investigated. Chronological order of these programs is such; Mercury, Gemini, Apollo, Skylab, Space Shuttle and International Space Station. Mercury program took place from 1961 to 1963 and it was in this 34-hour journey when after Yuri Gagarin food consumption (1962) in the space happened at first [9,10]. Within this space adventure having these two diverse features together; products in liquid form and preserved in easily-opened tube packages. Gemini program: Within the scope of this space program with varied missions between 1965-1966, a food menu was used in space for the first time and HACCP (Hazard Analysis and Critical Control Point) concept and practices that lay the ground for food safety in modern age was initiated. Apollo program took place between 1968-1972 with an aim to stay in space longer and in this program there were also researches on how to improve food quality and variety, Similar to Gemini program, foods in this program were inside simple and easy-to-open packages and could be consumed in dry, solid or liquid form to be heated in water or consumed in liquid form for the use of researchers [11]. Skylab program that took place between 1973-1974 was the space program containing the most comprehensive metabolic research till then and it is at the same time the program offering richest menu selection. As years passed, time spent in the space increased and dining turned into a serious activity; thus it was suggested to improve the presentations in food halls. It has been reported that in Skylab program, for the first time, freezer, heater units, sophisticated dining tables and cooking utensils for the astronauts were available. Space Shuttle program is a program that started in 1981 and continued even in the 2000s. Being a program with the greatest product selection, designs aiming to minimize waste were also presented within the context of this program. Additionally this is the first program in which all of the products chosen by astronauts were put on the menu that had reflected varied dietary choices. Russia became the partner country in a certain part of this program [12]. However, in essence, International Space Station is the most extensive and universal program. International Space Station program: It partially started with Space Shuttle program and in this program main goal is to spread globally the joint initiative with Russia and attain a truly international character and to make it easy to build a common future and solution for the humanity by integrating it to space researches from other countries [13, 14]. In line with this aim centers established in Europe, Japan and Canada now provide support to ongoing researches. In this active program, researches on the agricultural processes in space were also initiated. In this program food systems and food diversity was truly left to the astronauts' preferences and cultural effects. Currently the same program evolved into a global program enlightening space wonder of humankind [10, 15].

DIETARY NEEDS IN SPACE AND PLACE OF DAIRY PRODUCTS

The fact that space flights last long in many instances and there are longer stays in the space due to extended missions it is likely to witness different effects on humans. A grownup human being's basic daily needs under the conditions of earth differ from the ingredients required under space conditions. Space conditions may result in a myriad of physiological and psychological outcomes which can also affect their nutritional state. In the space nutrition plays vital role for both physical, psychological and overall health (immunity, musculoskeletal system) of humans [16]. Another variance related to dietary needs in space is the change in iron metabolism. Increased need for iron mineral in space environment could also give rise to hematological stages. A human being's iron need on earth is ~10 mg; in space however this ratio may escalate to the range of 15-18 mg though also dependent on the length of stay, gender and overall body form and some other factors [17]. In the same vein, elevated radiation and oxidative stress levels during flight could trigger diminished antioxidant levels during or after a space flight. Furthermore during this stage some of the other occurrences are decrease in blood cells, problems in physical movement, rise in dehydration and troubles in electrolyte/mineral balance [18]. Such lengthy space journeys can also have an effect on vitamin mineral need. Normally a human being's daily Calcium mineral (Ca) need is approximately 1000 mg whilst in space s/he required to consume around 20% more Ca because during these missions there is degradation in Ca absorption activity and a similar case also holds true for potassium intake. One of the biggest problems experimented after space flights is physical movement problems related to bone stability and it is attributed to a diet low in animal protein and potassium intake. This hypothesis also leads to claim that it could also be critical to preserve bone health also on Earth; that high protein intake could indirectly escalate body acidity whereas potassium mineral could, by bringing out the ingredients which would create basic effect indirectly, restore acid-base balance in human body [17]. One of the most salient problems experienced during space travels and during the time spent in space is bone loss and deterioration. Flexibility and weakness created on bones during the time spent in space cannot be cured only through Ca and vitamin D supplements. Yet adding the foods with higher ratios of Ca mineral and vitamin D to diet is reported to have lowering effects on bone loss and related ailments [19]. Endocrine system and gastrointestinal-immune system problems are also other frequent complaints related to space travels. In particular, systemic problems are more widely witnessed in space missions lasting 3 months and longer. Increasing probiotic and prebiotic ingredients in diet is one of the topics analyzed in this process. Although it has been reported that taking probiotic and prebiotic ingredients could relatively be helpful for immune system, there is not any sound data detected in literature [20]. Despite that, it is reasonable to claim that from a holistic perspective Ca mineral in particular, vitamin D, vitamin K, vitamin C, Fe mineral and relevant minerals and vitamins combined with probiotic supplements that a normal grownup would require on a daily basis could similarly play a vital role in meeting the nutritional needs in space. By including a wide range of nutrients, milk has been on front stage since ancient times as a fulfilling and nourishing product. Although a great composition of milk is water, remaining dry matter is reported to include more than 100 ingredients. Since its fat contains substantial fatty acids, milk fat is a valuable component. In the most common drinking milk, cow milk, there is 3-4 (m/m)% of fat though changeable with respect to regions [21]. More to that, milk can be classified as one of the biggest sources of calcium mineral in nature and milk is also a great source to get vitamin D [22]. Both of these ingredients offer sound benefits for a better bone health and overall development, growth and regulatory activities. Further to that vitamin B12 that is only available in animal products and endowed with a great number of functional effects; vitamin A, other B group vitamins and various mineral resources are also naturally available in milk. Added to that, in terms of proteins that have gained commercial popularity lately and also nutritional deficiencies, milk once again offers a great resource. It has been attested that carbohydrate intake combined with a specific ratio of protein resource is critical in achieving optimal body-fat ratio and regulated blood pressure [23]. Besides it has been acknowledged in many researches that essential amino acids within milk protein are critical in nutrition and muscle growth and biological value of milk protein is among the highest proteins on Earth [24, 4]. Another asset of milk products in particular fermented ones that can be defined as functional is probiotics, which add great nutritional value to milk when consumed enough daily intake values. Probiotics can be defined as the microorganism group offering benefits for the host agent once taken into body [25]. Many of the microorganisms forming probiotics belong to lactic acid bacteria and Lactobacillus and Bifidus are some examples to such bacteria. It has been reported that these bacteria render regulatory effects on gastrointestinal region and promote immune system. A vast majority of such bacteria already exist in the natural fermentation of dairy products. Yoghurt, kefir and specific types of cheese can also be considered to have such features. Supporting vitamin production and storing, anti-viral effect, anti-mutagen effect are some of the assets attributed to probiotics. Integral to these foods, probiotics provide benefits directly on the intestines and indirectly on immune system [26]. Dairy products are vital for human nutrition. However, dairy products are also needs to be enriched with different functional ways for human necessities. It is hard to enriched in particular cheese type of foods easily. In modern age, production technologies are changing and 3D production of dairy products and enriching of them would be easier than present production technologies.

EVALUATION OF DAIRY PRODUCTS IN SPACE FOOD PRODUCTION VIA 3D (3-DIMENSIONAL) AND 4D (4-DIMENSIONAL) PRINTERS

3-dimensional printer technologies seem to be a relatively novel technology but in reality, it stands before us as a technology with influences in the 20th century too. In relation to this technology, the very first application for patent belongs to Japanese Doctor Hideo Kodama in 1980 [27]. 3D printer technologies are a novel technology mainly having emerged in the field of material engineering, yet in modern age it became an attraction point for the products in many domains such as textile, food, health, electronics, automotive and fashion and by growing ever more, it turned into a technology inspiring both the academia and industry [28]. In 3-dimensional printers key principal of operation is forming basic configuration of the product to be applied by the assistance of a computer program through a specific modeling and performing printing stages by following critical process steps. The most critical and basic components of 3-dimensional printers are; sigma profiles (structure named as external skeleton), step motors (parts that facilitate movement of printer), nozzle (printer end to melt the filament), filament (material to be poured after melting) and hot bearing (the surface where the filament would be poured to form the desired material). Further to that, to achieve smooth operation of the system required stoppers, various mechanical and software parts are also available. Thus it is feasible to print the product if optimal dimensions and temperature are present and can be stopped if a problem occurs and reprogramming can be achieved [29, 30]. In addition to popular use of 3-dimensional printers, in almost all domains of life, there are ongoing technological researches that allow reuse of a material in different features and dimensions in the aftermath of its production in a single step. In the 1980s, advancement in three- dimensional (3D) printing technologies- also known as additive production or rapid prototyping- have brought with itself new developments too [31]. NASA is supporting a current project that is aimed to produce 3D foods for space missions. 3D food printing can be allowed nutrition enrichment and any shape of product with any ingredients and these products will be fresh that is very crucial for astronauts and their needs and requires [39]. Le Tohic et al. (2018) have been studied 3D cheese processing and its textural properties. In the study processed cheese were melted to prepare the base material to the printing process at 75°C. It was found that the hardness was less and meltability was higher for the printed cheese when it compared to commercial processed cheese [32]. Ross et al. (2021) were also obtained 3D printed cheese. In the study, different parameters (filling temperature, cheddar cheese ripening time etc.) effects on 3D printing were determined. Higher cheese pH values were found softer texture after printing and at higher temperatures (60°C) were also found softer and the texture was more resilient [40]. Another 3D printed dairy study was about high protein yoghurt production. 10% fat Greek type yoghurt was used and protein enrichment (7.5-12.5%) and using gelatine, WPI (whey protein isolate) effects on the physical and sensory properties were determined. It was found that WPI and gelatin were significantly affected the printability and the rheology. 12% of WPI addition was found more resilient. Gelatine addition was provided stable shape to printed product [41]. Introduced for the first time in 2013, there are current researches conducted in different domains on 4- dimensional printers. Dairy-product category represents a group with wide assortment and content of products and ingredients in dairy products and components with different characters related to such products can exhibit the feature of raw-material in 3-dimensional food production. To ensure that dairy products can be generated via 3-dimensional printers, it is of utmost importance to characterize these product formations quite well. At this stage, by identifying different formulations and providing best characterizations, it is essential to produce optimized products [32]. Production of dairy products with intense texture like yoghurt and cheese and based on this key principle under normal conditions, with different inputs that are particularly limited in cheese production. it appears to feasible to process-orientation and enriching stages via 3-dimensional (3D) printers. Producing of dairy products in 3-dimensional printers, it is important that present formulation be transferred to the system via nozzle under appropriate heat and viscosity. Heat is responsible from reactions such as Maillard that is expected in the final form of protein denaturation and product; thus it is vital to arrange heat in 3D production. Likewise, as for viscosity criteria, it can give insights about final product format and reticular structure to be formed by the proteins [33]. From that viewpoint, in the process of manufacturing dairy products by 3D printers building a widely comprehensive model that integrates such criteria as well as major parameters like microbiology and oxidation level are substantial for final product. While manufacturing industry is yet working on new applications, new materials and new 3-dimensional printers; Skylar Tibbits teaching at MIT (Massachusetts Institute of Technology) used for the first time "four-dimensional (4D) printing" term in his 2013 dated TED talk. It can allow static 3D printing objects to change their forms in time and thus introducing 4D printing/printer technologies [34]. The first paper on this topic was written before the end of same year. In this paper key objectives of 4-dimensional software were mentioned. In an age when 4-dimensional printing technologies were first mentioned, there was a description as 3D printing + time. In here it was stated that time was the fourth dimension but for the last few years, there has been another description joined with this one. The fact that form, feature and functionality of a 3D printing structure could change in time when exposed to a predetermined external stimulus such as heat, water, light, pressure, pH, sound etc. it became one of the most comprehensive definitions of 4-dimensional printers to present date [31]. The said situation is indeed related to building smart materials [35], key mechanism definitions for 4-dimensional printers are categorized below 5 different headings such as:

- 3-dimensional printing technologies:
- External stimulus
- Smart materials

- Interaction mechanism
- Mathematical model

To perform 4-dimensional software there is need for a material that would, under different operational conditions, undergo physical change leading to transformation in geometry and functionality. It is a must that relevant material would undergo change after being stimulated by a predefined external stimulus (heat, pressure, pH, light, UV etc.) so that this change would be performed by predefined stimulus parameters. This condition is essential to ensure that external stimulus feature and the material would take place within the framework of a specific mathematical expression [36]. To that end operation to take place (such as geometrical change under heat) must be defined in a mathematical model so that printer and material can provide proper function against the said external stimulus in that way. At the same time it is necessary to detect in what way and form the stimulus could be effective. This definition is known as effect mechanism of external stimulus. In defining all of them, to assure that the material would be produced in optimal forms and meet the desired conditions it is necessary that production be made by generating the best fitting 3-dimensional design [35]. Within that scope the most salient factor to consider is that if materials are appropriate for 4-dimensional (4D) printing, then, they are named as smart materials. Smart material concept refers to the kind of materials undergoing mostly physical, formal and occasionally physiochemical changes by reacting to the effects of an external stimulus. Although they undergo change as an effect of external stimulus (heat, pressure, light, pH, UV etc.) the main form of these materials is stored in their early memory. Yet these materials' shape memory effect and features defined as superelastic are critical for 4D software. Materials that have shape memory are listed below 5 main groups and these material groups includes materials with shape memory and performs alloy, ceramic, polymer, hybrid and gel features [37]. Although currently there are not any materials defined as to have smart features, it is estimated that in near future there will be a potential to manufacture food materials or food packages via 4-dimensional printers. At this stage it is suggested to emphasize particularly the value of shape memory polymer groups for the future. Shape memory polymers are elastic polymeric reticular structures composed of fixed points where there is molecular level cross linking and transition points that gain macroscopic shape by interconnecting these points. In these products fixed points allow to recall chemical or physical linking in the structure and entropic features of the polymer segments between them and its permanent shape. After ensuring that polymer structure gains permanent form, the order of processes is heating, deformation and cooling to give the product its temporary form [31, 38]. In order to produce relevant materials it is sufficient to have certain filament and basic raw materials and it appears that by following optimal modeling studies, it can be feasible to produce package materials with desired features and manage waste reduction as required. It has been agreed that in space 3-dimensional printers can be advantageous in developing different kinds of products and despite applications in a limited area with fewer number of materials, it is still viable to obtain a variety of products. Added to that in order to minimize the size of product packages it seems appropriate to make use of 4-dimensional printers (4D) in their design. By using limited place and energy with same-ingredient materials it is feasible to provide food for the astronauts/cosmonauts and residents in space setting and also to produce foods particularly cheese, yoghurt and similar dairy products. Hence it will be possible to produce the kind of processes with high nutritional value in lower cost and energy but also demanding higher costs and energy in a setting under harsh conditions such as space so that there will be a chance to shape the future of humanity.

CONCLUSION

It is an acknowledged fact that humanity has long been curious about space and has a past in which their future life was based on observing the sky. In near past there has been a great effort to satisfy their sky curiosity, establish life in sky and conduct trade operations as well. In the 2000s, steps were taken to meet humanity with this aim and agricultural operations already took place in space [13]. Researchers aiming to build a new life in the new age not only want to adapt their life on earth to their new habitat but also seek to keep their diet almost the same. Nevertheless considering the effects of space on human lives the fact that milk and dairy products also play a vital role becomes evident. Since it is infeasible to send tons of liters of milk from earth, it is more reasonable to consume products such as milk powder that is easy to transfer and store, and can be changed into milk form when needed. If combined with different technologies products such as cheese and yoghurt we consume on earth could also be offered in space for human consumption. As 3-dimensional printers can be used in product manufacturing and 4-dimensional printers in product packaging it will be possible to consume traditional earth foods in space and also to produce the kind of foods integrating ingredients essential in space could be procured in a practical way.

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