韓國營養學會誌 : 第16卷 · 第 3 號 · 1983
Korean J. Nutr. Vol. 16, No. 3, 1983

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Nutritional Properties and Utilization of Bovine Whey

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牛乳 乳漿의 營養學的 特性과 利用

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－國 文 抄 錄－

새로운 기술과 연구에 따라 유장의 생산과 소비는 증가 일로에 있다.

본 논문에서는 유장의 조성과 영양학적 그리고 기능적 특성이 고찰되어졌다. 유장에는 단백질, 유당, 젖산, 무기물들, 미량성분들, 비타민들과 효소들이 함유되어 있다. 각 조성 성분들은 사용 목적에 따라 각각 다른 방법들로 분류될수 있다. 유장은 높은 영양가치와 우수한 기능적인 특성으로 인하여 식품 첨가물로서는 물론 질병 치료제로서 이용가능성이 다방면으로 제시되고 있다.

INTRODUCTION

Whey is the liquid part of the milk remaining after the separation of curd in cheese-making. The two most important types of whey are rennet and acid whey. Rennet whey is obtained during cheesemaking with the use of rennin or rennin like enzymes, while acid whey produced after precipitation of casein with acid at pH 4.6[1),2)].

In recent years, utilization of whey has been necessary not only because of environmental pollution but also because of world wide problems of food resources.

접수일자 : 1982. 6. 28.

There has been a steady upward trend in the utilization of whey for human food during past decades due to a better understanding of the unique nutritional, biological and functional properties of whey components[3)].

In this paper, some nutritional, physiological characteristics and aspects of utilization of whey for human foods with reference to its therapeutical value have been described.

NUTRITIONAL VALUE of WHEY

Whey contains protein, lactose, minerals, trace elements, vitamins, lactic acid, and enzymes. The

Table 1 shows the main composition of whey. The composition varies with the type of milk, the sort of cheese being made, and the mode of separation and concentration. Fluid whey is a dilute solution of about 6.5% total solids.

Table 1. Composition of bovine whey[4)5)6)] (per 100g)

	Sweet whey	Powdered whey
Main nutritive substances		
Water	93.6 g	7.10 g
Protein	0.82 g	12.0 g
Fat	0.24 g	1.2 g
Carbohydates	4.70 g	71.5 g
Minerals	0.58 g	8.20 g
Lactic acid	0.05 g	2.3 g
Minerals & Trace elements		
Sodium	45mg	1.29 g
Potassium	29mg	1.86 g
Magnesium	1mg	180mg
Calcium	7.9mg	890mg
Iron	0.1mg	0.9mg
Zinc	0.05mg	2.1mg
Phosphorus	43mg	576mg
Chloride	67mg	
Vitamins		
Vitamin A	0.003mg	0.015mg
Vitamin E	0.024mg	0.06mg
Vitamin B_1	0.037mg	0.49mg
Vitamin B_2	0.15mg	2.50mg
Nicotinamide	0.19mg	0.8mg
Pantothenic acid	0.34mg	1.5mg
Vitamin B_6	0.042mg	0.6mg
Biotin	1.4 μg	0.043mg
Folic acid	1.0 μg	0.012mg
Vitamin B_{12}	0.2 μg	2.4 μg
Vitamin C	0.89mg	1.41mg

2.1. Whey proteins

The whey proteins make up about 20% of the proteins present in milk including about 5% of nonprotein nitrogen and proteose peptone[1)].

The whey protein differs casein from both\ in structure and properties. The whey proteins are not associated into micelles but are moleculary dissolved. These are susceptable to heat denaturation[7)]. The major whey proteins have compact and globular conformations with a substantial amount of helical structure. This conformation is probably due to the uniform distribution of acidic/basic and hydrophilic hydrophobic amino acids along their polypeptide chains[3)].

Whey proteins contain β-lactogbbulin, α- lactalbumin, serum albumin, immunoglobulin, proteose peptone, lactoferrin, transferrin, and some enzymes. They have different structural, functional, and physsilogical characteristics[1)7)8)9)]. The characteristic functions of whey proteins are described briefly as follows : The principal whey proteins like β- lactoglobulin, α-lactalbumin, and lactoferrin are synthesized in the mammary gland : the other major whey proteins such as serum albumin, transferrin, and immunoglobulins are derived from the blood[7)9)].

β-lactoglobulin is an amino acid carrier and major protein constituent with the approximate content of 50% of whey proteins[2)]. The physiological function of β-lactoglobulin has not yet been explained. There has, however, been some speculation that it plays a regulatory role in the phosphorus metabolism[10)11)]. It probably has secretory function[12)] and contains active-SH group in the form of a cysteine residue[13)14)]. These groups are thought to be involve in the cooked flavour and complex formation with k-casein that develops in heated milk[7)13)].

α-lactalbumin is the second most abundant constituent with the content of about 18% in the whey proteins and has been recently discovered to be essential substance of the lactose biosynthesis[1)11)15)16)17)]. It is of interest that α-lactalbumin contains no free-SH groups, though its content of cystine is high[13)]. α-lactalbumin content of milk seems to be related to the lactose level[18)].

Immunoglobulins, containing about 11% of whey proteins, are glycoproteins. They possess antibody activity, which is an important protective function as a source of passive immunity in the development of the neonate[1)10)12)16)17)19)20)]. Blanc[18)] and Hilpert et al.[21)] reported that the immunoglobulins also produce protective effect to the babies against diarrhea, which is caused by pathological coli phylum. The immunoglobulins are the most sensitive to heating followed by serum albumin, β-lactoglobulin and α-

lactalbumin[22].

Serum albumin contains approximately 5% of whey proteins and is characterized by micro- heterogenity[1)14)].

Proteose peptone, as consisting of mixture of fragments of milk protein molecules, contains about 16% of whey proteins. It is characterized as a phosphoglycoprotein with thermostable nature[1)12)14)16)] and comprises relatively high concentration of glutamic acid and asparaginic acid[19]. Proteose peptone fractions are not precipitated when the whey is boiled and then adjusted to pH 4.6[18], but can be precipitated by 12% (w/v) trichloroacetic acid from the liquid remaining after coagulation and separation of heat-labile protein fractions[23].

Lactoferrin and transferrin fix and transport iron and have a nutritional function as well as an anti-bacterial action[12)17)18)19)24)25)26)]. The bacteriostatic activity is due to the fact that the lactoferrins interfere with bacterial iron supply because most bacteria require iron for growth[18].

Whey contains a number of enzymes, predominantly catalase, lysozyme, ribonuclease, and lactoperoxidase[19]. Lactoperoxidase is an iron-containing enzyme accounting for about 1% of total whey protein content. It is characterized by its heat stability and natural antibacterial activity[25)27)].

Lysozyme has also an anti-bacterial effect directed principally against gram positive bacteria[18)20)27)].

The amino acid content of whey proteins, given in Table 2, complements the assortment of essential amino acids present in casein and therefore increase the nutritive value of milk. It is well known that protein value of whey is much higher than that of casein. This superiority is due to the high content of the sulphur-containing amino acids in the albumins[9] (Table 2).

Whey proteins have similar amino acid composition as that of human milk and meet all the requirements for the biosynthesis of cell protein. Whey protein is rich in lysine, tryptophan, isoleucine and threonine[29)30)]. Whey proteins have been regarded as superior to most other proteins in animal nutrition : it has been quoted frequently that the daily requirement of amino acids can be furnished by 14.5g of lactalbumin, or 17.4g of whole egg protein or 28.4g cow's milk[25].

Forsum and Hambraes[31] reported that the biological value and true digestibility of the proteins were high in all products although the concluded that the nutritional quality of the whey protein porducts was sufficient to be of nutritional significance in human diet.

According to Jakobsen[32] the absorption of orotic acid results in a saving of energy and in the improvement of capacity of the liver, as RNA is rapidly regenerated to the maximum. These conditions are of special importance when the organism is under stress.

Many feeding experiments have shown that the whey protein as water-solved nutritive phase can be metabolized and absorbed quickly in the body[29].

Since early times it has been well known that the whey proteins play great role as a natural medicament for the therapy of diseases and as a prophylactis to maintain the power of resistance[29]. Whey proteins function as buffer system in stomach[33)34)35)].

Table 2. Amino acid composition of bovine whey proteins and whey protein concentrates[5)28)] (g/100g)

Amino acid	Sweet whey	Powderd whey	Whey protein concentrates *
Isoleucine	0.047	0.69	6.2
Leucine	0.067	0.99	9.9
Valine	0.041	0.56	6.0
Methionine	0.012	0.18	2.1
Cystine	0.016	0.24	2.4
Phenylalanine	0.021	0.31	3.3
Tyrosine	0.008	0.12	2.1
Threonine	0.044	0.64	7.0
Tryptophan	0.009	0.14	2.4
Lysine	0.050	0.73	9.0
Histidine	0.010	0.15	1.8
Arginine	0.015	0.22	2.4
Aspartic acid	0.074	0.15	10.5
Glutamic acid	0.036	0.09	17.4
Proline	0.045	0.69	6.1
Serine	0.035	0.54	5.2
Alanine	–	0.51	4.7

* = g amino acid / 16 g N

With special methods of fractionating, reverse osmosis, gel filtration, electrodialysis, ultrafiltration, ion exchange and precipitation, it is possible to produce such high content of whey protein as whey protein concentrates, which nutritional data are shown in the Table 2.

2.2. Lactose

Lactose is a disaccharide formed by linking two six carbon-containing sugars together. These constituent hexoses are D-glucose and D-galactose. On splitting the β-linkage between them two sugars in the monosaccharide form will be released[17)36)]. There are three major chemical derivatives of lactose, lactitol and lactobionic acid[38)].

Lactose supply activates the peristalsis of intestines and intensifies the vitamin absorption[24)29)]. Lactose plays an important role in bone development through increased calcium absorption and metabolism[29)30)37)39)40)]. Lactose impacts are absorbed easily and transport minerals, i.e. phosphorus, magnesium, potassium and sodium as lactose complex to required organs[29)]. Lactose is important in maintaining balanced blood cholesterol[23)], is absorbed slower than saccharose and therefore works as persevering energy donor. Lactose is also a desirable nutrition source for the physiological intestinal flora [24)41)42)]. Whey has also laxative reaction because of effect of lactic acid bacteria on lactose[29)30)40)]. Lactose has been controversial because the significance of clinically induced lactose intolerance has been frequently discussed. The solution to the problem is either to reduce or to pre-hydrolyze it with lactase addition.

2.3. Lactic acid

Lactic acid, a decomposition product of carbohydrate metabolism, has been detected in three different forms as L(+)-lactic acid, D(-)-lactic acid, and optical inactive form DL-lactic acid.
The quantitative relation of these enantiomers is dependent upon the quality of milk, end-pH, the applied microorganisms and the art of fermentation [42)43)44)46)]. Animal organs transfer the D(-) lactic acid insufficiently and slowly than the physiological L(+)-lactic acid. In the practical nutrition it is well known that the L(+)-lactic acid is good for adults[43)44)45)47)]. L(+) lactic acid is a stimulationless organic acid, which helps in the developments of physiological intestinal flora and normalization of digestion process[29)30)42)47)]. Babies have lactic acid bacteria flora, Lactobacillus bifidus, which transfer lactose to L(+)-lactic acid[29)43)47)].

2.4. Minerals and trace elements

Whey contains about 0.5-0.8% minerals[4)5)6)]. Minerals as buffer system, stabilize the pH-value, raise the solubility of colloids, transfer the stimulating impulse and regulate the metabolisim of cell. Whey minerals promote its utilization in organ as a soluble phase[29)30)].

Calcium is an important substance of bone and teeth for children and adults. Absorption of calcium through milk stimulates the other nutrients, such as lactose, lysine, valine, citrate etc.[33)35)]. The trace elements have very small concentration in the metabolism as compared to the minerals.

2.5. Vitamins

Whey contains water soluble vitamins, i.e.vitamin B_1, B_2, different quantities of vitamin B_6, pantothenic acid, choline, biotin, vitamin B_{12}, folic acid and a little of ascorbic acid.

Vitamin B group is rich in the whey and plays

Table 3. Functional properties of whey proteins [49)50)51)]

Property	Functional terms
Organoleptic	Flavour, odour, texture, colour
Appearance	Turbidity, colour
Hydration	Solubility, dispersibility, swelling, viscosity
Surface active	Emulsification, foaming, whipping, baking
Structural	Elasticity, cohesion, texturization, aggregation
Textural	Viscosity, adhesion, aggregation, texturization
Rheological	Aggregation, gelation, dough formation, extrudability
Other	Compatibility with components and processing conditions

an important role for cell respiration and cell regeneration. This vitamin B group regulates the decomposition of carbohydrates and takes part in the metabolism of heart, liver, and nerve[29)48)].

Vitamin B_2 functions as a catalyst in respiration chains, biochemical photosynthesis and dehydration of amino acids[29)30)]. The yellow-green colour of whey is due to the presence of vitamin B_2[48)].

Vitamin B_6 can be synthesized partly during the lacto-fermentation of whey and results in 30% more of vitamin B_6 than native whey due to microbial activity[29)].

Nicotinic acid as a component of co-enzymes, is also involved in the protein metabolism and cell respiration[29)30)].

UTILIZATION of WHEY

Whey utilization in its most sophisticated and profitable sense implies that whey as a concentrate or fraction will be used by man or animal in the form of a nutritious food or some essential components of food or as resource of pharmaceutics.

Table 4. Examples of whey based foods[6)50)51)53)54)]

A. Foods supplemented with sweet whey or its derivatives	
Ice cream	Candy coatings
Ice cream coatings	Fudge, caramels, chocolate
Bread	Margarine
Sweet rolls	Syrups
Crackers	Infant foods
Cookies	Toppings
Cakes	Meat sauces
Icings	Soups
Snack foods	Soft drinks
Gravy mixes	Cheese foods
Seasoning mixes	Dulce de leche
Orange juice	Puddinge
Meat products	Compound coatings
B. Foods supplemented with acid whey or its derivatives	
Fruit beverages	Bread
Fermented milks	Crackers
Cheeses	Sherberts
Cheese powders	Sausage binders
Salad dressings	Procese cheese foods
Cheesedips and spreads	
C. Fermented foods from whey or its fractions	
Vinegar	Ethyl alcohol
Lactic acid	Single cell protein
Wine	Dough or doogh yogurt
Cordials	Cultured milk products
D. Others	
Food acidulant	Macaroni and pasta
Whey butter	Protein foods enrichment
Chiffons	Lactose hydrolyzed whey concentrates
Riboflavin concentrates	

3.1. Utilization for foods

The fresh liquid whey can be utilized without further processing as drinking beverage. Although, most part of the fresh liquid whey is usually defatted by centrifuge, pasteurized and can be concentrated, dried or modified depending on its usage. It can be also fractionated, hydrolyzed, demineralized, enriched with other components of milk and fermented.

The main industrial uses of whey are in the manufacture of whey protein concentrates, lactose, whey paste, dried whey, and various fermented products such as lactic acid and ethyl alcohol.

Whey proteins, as mentioned above, have adequate essential amino acids and highly nutritionally complete as well as posses many excellent functions as food ingredients. Table 3 contains some important functional properties of whey proteins.

In the selection of protein supplementation a high ratio of protein to total calories-so called nutrient density-is likely to be sought : Whey protein concentrates would be ideal[25].

There is considerable variation in the functional characteristics due to difference in the extent of removal of lactose, salts and other nonprotein components, protein denaturation or the pressure of residual protein precipitating agents[49]. One can choose from whey based ingredients to meet the functionality required in any particular food system. Some functional properties of whey protein can be improved with physico-chemical or enzymatical modification[52]. Denaturation of the whey protein molecule in the proper condition can also improve the functionality due to an unfolding of the molecule to expose hydrophobic amino acid residues[8].

The utilization possibilities of whey are in a wide varieties of foods and related products. Some typical ideas for whey foods are outlined in Table 4.

Enhancement of the biological value of nutritionally poor proteins is probably the single most valuable property of milk protein[55]. Since good quality protein is an essential ingredient for human nutrition, whey or whey proteins can be used to extend current milk supplies in developing countries thereby contributing to the abatement of protein-calorie malnutrition[56]. The supplement of whey protein for diets consisting of rice, corn or wheat, which are the major grain foods eaten in the developing countries, is very important to improve the malnutrition. In the case of rice, fortified with whey, rice can fulfill the requirement for lysine. With corn meal, whey supplement provides enough lysine, sulphur amino acids, and tryptophan[36].

Some applications of lactalbumin has been suggested to protein fortification of such foods as sausage, other commuted meats, breakfast cereals, breads, confectionary and roller-dried baby foods[57].

Lactose is the only milk sugar, which comes from mammalian sources, produced industrially and its application in food products has been on the increasing trend. Lactose has unique physico-chemical properties that food scientists use to improve their food products[39][40][58]. Use of lactose in foods is based on relative sweetness, hygroscopicity, promotion of browning reaction, protein stabilizing effects, alteration of crystallization, sensory discrimination or flavour accentuation, optimalization of consistence and texture, raise of viscosity, selective fermentation abilities, carrier of colour and enhancement of mouthfeel[3][25][40][57][59]. Most applications of lactose are in bakery, meat manufacture, candy, sweet cakes, dried soups, simulated human milk, baby foods, aroma components, lactose syrup and pharmaceutics[40][54][58][60]. Lactose can be also applied to the animal feeding and to the single cell protein production[60].

The hydrolysis of lactose can be effected by mineral acids, ion exchange resins or enzyme[61]. If the lactose is hydrolyzed, it includes reduced lactose content, prevention of lactose crystallization, increased carbohydrate solubility, increased sweetness and more readily fermentable sugars[62]. The hydrolyzed lactose provides low-lactose dairy products for lactose intolerant individuals.

Riboflvin, which is also synthesized by fermentation of whey can be used for riboflavin concentrate, butyl alcohol and feeding material[54].

In addition to its economy, functionality, and nutrition, whey is used in food products as a flavour contributor[39].

3.2. Utilization for therapy

Since early history of mankind whey has been utilized for natural cure either through drinking or

bathing. The whey cure has been applied especially for the consumptive, jaundice as well as stomach diseases. The patients drink about 0.25-0.5 litre with mineral water and mixture of scurvy- grass, sorrel, water-cress, beaver-clover or other herb - lotion[63]. Whey has been also used as a pharmaceutical drug for soothing, salves for burn, a skin balm and to inspire vitality and to restore hair[6].

Whey diets support the regeneration of cell proteins and enzymes in liver with high potential of physiological amino acids[29]. Whey can protect the liver, which is the central detoxication organ of human body[32)39)48]. Due to high contents of biologically valuable compounds and buffering effect, whey concentrates have been utilized to treat a certain phase of stomach disease, like hyperacidity and duodenal peptic ulcer[29)33)34)55]. The use of whey protein fraction in the dietary treatment of phenylketonuria has been suggested[64)65].

Whey is not like meat and other food protein sources, containing no purine, has advantages to demolite the uric acid depot by acceleration of excretion and to regulate continually the uric acid metabolism. Therefore whey is used for therapy diet of gout[29)35)39)66)67]. Karp[68] reported that 100 g servings of whey based beverage, cheese type spread, and frozen dessert would supply approximately 11, 20, and 13%, respectively, of protein in the standard diet for patients with chronic uremia. It was pointed out that whey protein can be also applied to reduce the level of blood cholesterol and to prevent indirectly the arteriosclerosis[34].

Shahani and coworkers[3)56] have developed a special dietetic foods, which is based on whey for cardiac disorder. They also recommended other formulate foods for convalescing patients by providing enzymatically hydrolyzed proteins for easier and quicker digestion.

Cystic fibrosis, a genetic disease manifested by the secretion of sticky mucus in the lumen of the respiratory and digestive tracts and a deficiency of pancreatic enzyme activity in the small intestine : both these abnormalities contribute to reduce metabolism of ingested fat and protein[69].

Since the nutritional composition of whey is similar to the content of human milk, it is a better artificial food for babies and children[29]. The feeding of humanized milk exerts considerably low osmolar loads and increase nitrogen retention and utilization[56].

Because of relatively low content of aromatic amino acids, phenylalanine and tyrosine, whey proteins are suitable as protein source in the dietetic treatment of patients with a disturbed metabolic capacity of these amino acids, i.e. tyrosinemia and hyperphenylalaninemia[35].

Manson[70] has reported that the immunoglobulins and lactoperoxidases can be used as pharmaceutical preparations due to their antibacterial properties.

Due to slower resorption and stabilizing effect of blood-sugar level, Kubler[67] recommended lactose as useful dietetic supplement for diabetes mellitus.

Lactulose is an isomer of lactose and has received attention in the area of infant nutrition as bifidus factor in the intestine and in relieving constipation[36].

L(+)-lactic acid has also curing effects for psoriasis, milk crust and dermatitis[47].

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