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Cottonseed protein: What does the future hold?

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Abstract. Cottonseed protein has the potential to increase the world's food supply while decreasing the incidence of malnutrition among the world's hungry. Nutritionally, cottonseed flour compares favorably to other animal and vegetable protein sources, as it is low in fat and contains a substantial amount of high biological value protein. Animal studies, as well as human research, using gossypol-free glandless cottonseed flour have shown that cottonseed protein promotes growth, increased weight gain, and a positive nitrogen balance. Cottonseed protein food products have been shown to be a healthy addition to the diets of children, college-age women, and the elderly. With its light color and bland flavor, cottonseed has many uses in the food processing arena. Baked goods, snack foods and candy, as well as pet and livestock feed are just a few successful products developed utilizing cottonseed protein.

Introduction

The cotton plant (*Gossypium hirsutum*), one of the world's major sources of oilseed products, has long been used in human nutrition. While the edible oil represents 50% of the total revenue obtained from processing a ton of seed, the importance of dietary cottonseed protein has only recently been identified. Worldwide, plant sources contribute approximately 70% of the consumable protein. There is great potential for cottonseed protein, as it is less expensive and easier to obtain than animal protein and may be easily incorporated into the diet as a high quality protein that will promote growth [1].

Cottonseed has the potential for meeting the needs of the world's increasing population and improving its nutritional status. Currently more than 2/3 of the world's population has an inadequate food supply, and protein malnutrition is second in importance only to total food supply in terms of being a major health problem. Eighty thousand children are born daily who will not reach the age of five because of malnutrition and starvation. Consequently, new forms of protein must be made available to combat this starvation and malnutrition. Since cotton is raised in many impoverished parts of the world, it can indeed play a major role in meeting these needs [1].

A byproduct of the cotton fiber and oil production, cottonseed flour has a relatively high biological value (55–68% protein dry weight). Its protein

efficiency ratio (PER) is greater than the PER in a number of other major vegetable proteins. Many research investigations have substantiated the belief that cottonseed protein can promote growth and maintain health in many segments of the population. Since cotton is grown in many areas of the world where protein-calorie malnutrition (PCM) exists, and since cottonseed flour has successfully been incorporated into a wide variety of food products and typical native dishes, this plant clearly has great potential [1].

Nutritional value of cottonseed meal

For every 500 pounds of cotton fiber processed, there are 165–170 pounds of cottonseed protein produced [1]. The major usuable components of the cotton plant are diagramed in Figure 1 [1]. The protein fraction contains a very good ratio of amino acids, with lysine, threonine, methionine, and isoleucine being the limiting amino acids as shown in Table 1 [2–4]. When one looks at the overall nutrient content of cottonseed flour (Table 2) and compares the quality to protein from other vegetable (soy) and animal (hamburger, milk) sources, the cottonseed protein compares favorably in that it contains a low amount of fat and a substantial amount of protein [5].

Animal studies with dietary cottonseed proteins

Various animal studies have been used to identify the nutritional advantages/disadvantages of adding cottonseed protein to the diet and to examine how methods of food preparation impact the nutritive value of cottonseed

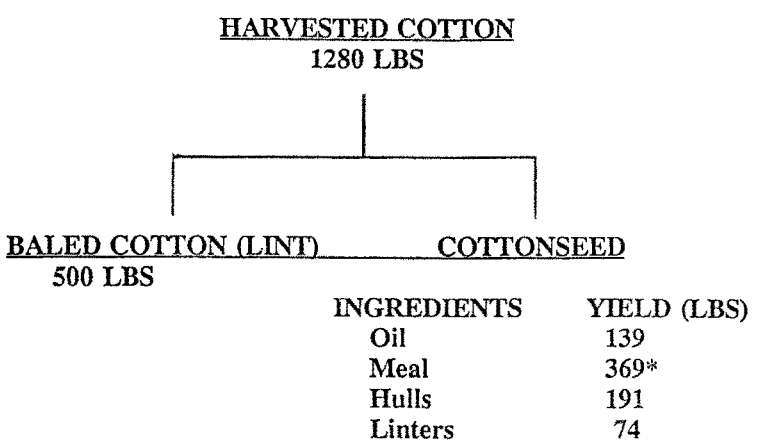

Fig. 1. Diagram of approximate yield of the components of the cotton plant*.

Note: This meal contains approximately 165–200 lbs. of protein.
* See Blankenship & Alford (1983) [1].

Table 1. Amino acid composition of glandless cottonseed flour and glandless cottonseed kernels (mg/gm protein)

Amino acid	Glandless cottonseed flour[1]	Glandless cottonseed kernels[2]	Human milk[3]
* Lysine	48.0	45.0	67.5
Histidine	31.0	27.0	25.0
Arginine	130.0	121.0	38.3
Aspartic acid	110.0	91.0	84.2
* Threonine	34.0	30.0	44.2
Serine	39.0	42.0	45.8
Glutamic acid	208.0	216.0	150.8
Proline	46.3	34.0	70.8
Half-cystine	28.0	12.0	13.3
Glycine	47.0	41.0	25.0
Alanine	45.0	39.0	39.2
* Valine	46.0	44.0	45.0
* Methionine	16.0	14.0	15.8
* Isoleucine	35.0	30.0	40.0
* Leucine	68.0	54.0	86.7
Tyrosine	31.0	29.0	32.5
* Phenylalanine	64.0	54.0	34.2
Available lysine	45.0	41.0	–
* Tryptophan	–	12.0	–

* Essential amino acid.
[1] See Martinkus et al. (1977) [2].
[2] See Lawhon et al. (1977) [3].
[3] See FAO (1972) [4].

Table 2. Selected nutrient comparisons of various protein foods*

Nutrients	Partially defatted cottonseed flour (100 g)	Defatted soy flour (100 g)	Extra lean ground beef broiled (100 g)	Dried skim milk (100 g)
Calories	360.0	327.0	256.0	358.2
Protein (g)	42.0	51.5	25.4	35.1
Carbohydrates (g)	40.0	33.9	0.0	52.2
Fat (g)	6.0	1.2	16.3	0.8

* See Pennington (1994) [5].

flour. Early researchers confirmed that cottonseed protein meal and flour were effective growth-promoting substances [6]. The potential of cottonseed protein as a nutritional source was also reported in 1944 by Zucker and Zucker [7]. In their study, superior growth promotion was exhibited in animals fed a wheat flour mixture containing 5% cottonseed flour.

Because the majority of cottonseed grown in the world has historically

contained a potential toxin, gossypol, studies of wholesomeness were required by the Food and Drug Administration (FDA) to establish safety for human consumption. Glanded cottonseed fed to monogastric animals had been shown to reduce the oxygen-carrying capacity of the blood and result in shortness of breath and edema of the lungs. Paralysis had also been shown to be a potential problem. The toxicity of gossypol affected various animals to different degrees. Rats were shown to lose appetite, become listless, stop growing, and develop a rough hair coat [8]. A contraceptive effect in humans from small levels of 'free' gossypol had been reported by Chinese scientists [9]. In a safety study by Pyke [10], 20% glanded cottonseed kernels added to lab chow did not interfere with reproduction.

Gossypol can be removed from cottonseed protein by treatment with a 2% ferrous sulfate solution [11]. This has led to a decrease in the toxicity problem. A genetically-engineered 'gossypol-free' cottonseed will soon be available that will increase the 'gossypol-free' cottonseed supply even further [12]. Glandless cottonseed kernels contain very low levels of gossypol and were used in initial animal studies.

Animals fed glandless cottonseed protein had the same quantity and quality of offspring as those animals fed casein protein [10]. Early rat studies showed that raw, roasted, and cooked glandless cottonseed flours were safe and supported growth at normal levels [13]. Cooked and roasted products were used more effectively than either raw products or the control diet (rat chow). Body weight, growth, and food consumption were the same for all groups. The number of litters born, the litter size, and food consumption were similar among groups.

The ability of cottonseed protein to support bone growth and development has also been documented [1]. Animals fed 9 and 18% calories from protein containing either 0, 50 or 100% cottonseed protein showed a calcium increase when casein was the sole protein source and a decrease when cottonseed was the only protein source. Positive calcium balance, however, was maintained with the animals fed a diet containing a casein-cottonseed mixture. Regardless of the protein source, a higher body weight and superior skeletal maturation were obtained with the diet that contained higher protein levels.

In a nutrient analysis study, the bioavailability of zinc from defatted glandless cottonseed was investigated using adult female rats [14]. Cottonseed contains zinc and phytic acid, which are both inhibitors of trace elements bioavailability. In this short-term study, a direct relationship was drawn between weight gain, feed intake, and zinc intake. Animals fed a cottonseed diet showed superior weight gain when compared to animals fed egg white protein diets, suggesting that cottonseed may be used as a protein supplement without adverse effects from its increased zinc concentration.

Other research studies looked at the effect of dietary protein on cholesterol metabolism and gallstone formation. Proteins derived from animal sources have a greater tendency to increase plasma cholesterol than do proteins derived from plant sources. The primary cause of cholesterol gallstones is

supersaturation of bile with cholesterol. Several studies [15–17] were conducted at Texas Woman's University (TWU, Denton, Texas) to determine the possible role of cottonseed protein in the prevention of cholesterol gallstones and the involvement of cottonseed in lipoprotein metabolism. Hamsters were fed either casein, cottonseed, or soy protein. A significant decrease in gallstone formation was exhibited with vegetable protein (cottonseed and soy) diets. When casein was used as a protein source, it was shown to be hypercholesterolemic. In another hamster study, a significantly greater amount of gallstone formation occured in casein-fed animals. No gallstones were found in the cottonseed-fed animals. It is suggested that increased biliary cholesterol and decreased bile acid concentrations in the casein-fed hamsters are the mechanisms by which gallstones are formed. On the other hand, serum cholesterol in the casein-fed animals did not significantly differ from that in the cottonseed-fed animals, and no relationship was found between serum HDL-cholesterol and biliary cholesterol concentrations [17].

To further investigate the mechanism behind dietary proteins and their effect on serum cholesterol metabolism, amino acid ratios have been studied. Rats were fed diets containing casein, cottonseed, arginine-supplemented casein, or lysine-supplemented cottonseed. Rats fed the casein or lysine-supplemented cottonseed diets exhibited increased serum cholesterol and HDL-cholesterol concentrations, and increased lecithin:cholesterol acyltransferase (LCAT) activity. The group fed the arginine-supplemented casein diet exhibited decreased serum- and HDL-cholesterol concentrations. It can be hypothesized that the cholesterol-lowering effect of plant protein is partially due to the ratio of arginine to lysine in the diet [8].

Human studies with dietary cottonseed proteins

Epidemiological studies

Numerous studies have shown the benefits of feeding cottonseed flour as part of the diet of malnourished or undernourished children [19–21]. Scrimshaw et al. [22] fed a flour mix (38% cottonseed flour) commonly called *INCAP Vegetable Protein Mixture* to malnourished South American children and reported favorable nitrogen balance and growth. Graham et al. [23–24] fed cottonseed flour to severely malnourished Peruvian infants and found impressive weight gain and nitrogen retention. It was concluded that when cottonseed flour was fed at a level in which the protein constituted 8–10% of the total calories, it could be used as the primary protein source for infants and children. In Africa, a cottonseed flour blend was shown to lead to accelerated growth in young children over a six month period [25]. Furthermore, it was demonstrated by Srikantia and Sahgal [26] in India that low gossypol cottonseed protein was beneficial for malnourished children.

Clinical studies

Clinical studies at TWU have shown that cottonseed protein is a safe and nutritious product for children [27–28]. When cottonseed meal was provided to six 12-year-old children for six months as 30% of the protein intake, several positive results were obtained. Serum hemoglobin, hematocrit, albumin, globulin, ascorbic acid and carotene concentrations were all normal. Vitamin A concentration was higher in the cottonseed-fed group than in the control group. Both serum calcium concentration and bone development were normal. When height/weight measurements were taken, the cottonseed-fed group showed a significant gain in their height. Protein metabolism was normal. Serum cholesterol showed a nonsignificant decrease in the cottonseed-fed group.

To determine the nutritional quality of cottonseed protein, several studies at TWU investigated nitrogen balance in adults consuming various cottonseed protein diets. In a study with twelve young university women fed liquid formula diets containing 95% of their protein as cottonseed protein, it was shown that cottonseed protein could adequately maintain nitrogen balance over a five week period [29]. In a subsequent study, seven women, ages 18 to 23 years, were fed cooked cottonseed products for 42 days. It was concluded that cottonseed flour, when incorporated into baked products, maintained nitrogen balance with no change in nutritional status [30]. A similar study by Alford and Onley [31] was designed to assess the minimum amount of nitrogen from deglanded and glandless cottonseed protein that was required to maintain nitrogen balance in fourteen university women ages 19 to 25. After an initial protein level of 15% of total energy intake, the protein level for each participant was decreased until a point was found at which positive nitrogen balance could not be maintained. Nitrogen intakes were similar for the two forms of cottonseed with a mean of (0.11 g N/kg/day).

Numerous other studies done at TWU have shown that cottonseed flour, when consumed by young women, can be part of a nutritious food product [32–34]. In all studies, serum lipid profiles either improved or did not change. Serum calcium concentrations also did not decrease, and serum proteins were not affected. Proske [35] has reported that healthy female volunteers fed cottonseed bread and oat bread exhibit significantly lower plasma glucose responses than when they were fed white bread. Sneed et al. [36] reported normal fasting free amino acid concentrations in college women who consumed a diet which contained a significant amount (95%) of glandless cottonseed protein.

In further studies, eight young Down's Syndrome women, who were fed a diet that contained 50% of its protein as cottonseed protein for three weeks, showed a significant improvement in what otherwise were low serum immunoglobulin values (IgA). Subjects also showed improvement in facial rashes and eyelid inflammation. Three months after the diet was stopped, the abnormal immunological values had reoccurred [37].

Cottonseed protein has also been shown to be a healthy food product in studies with elderly women. A study by Stephens [38] showed similar serum cholesterol concentrations in elderly subjects who consumed a balanced diet containing cottonseed products and control groups. Other studies have shown that serum lipid profiles either a improve or do not change with cottonseed protein diets [40]. Hemoglobin, hematocrit, and total protein concentrations, as well as albumin/globulin ratios tend to remain stable.

New directions for clinical research with cottonseed protein

The role of arginine in the maintenance of good health

Cottonseed protein is the only food product that is known to contain *very* significant amounts of arginine. In recent years arginine has been implicated in several animal models to play a modulating role in the process of carcinogenesis [40–47]. Arginine has been shown to protect against the growth of transplantable tumors and the tumorigenicity of carcinogens [48]. Arginine has also been shown to have a preventative role in the progression stage of cancer in that it is used by parts of the immune system (macrophages) to produce nitric oxide (NO) which has a toxic effect on bacteria and tumors [49]. Research has shown that endothelial cells can convert arginine to NO which can then cause a relaxation of cardiovascular smooth muscle cells. Arginine, via NO, is also a principal regulator of blood pressure.

New food products which contain cottonseed protein

Favorable clinical research on the nutritional uses of glandless cottonseed has expanded its dietary uses. Originally this protein source was used as a high-protein animal feed, however, it has presently become an important seed in the diets of humans [1]. Early studies at TWU paved the way for the future use of cottonseed protein products in a variety of foods [50–51]. Today, research is on-going at TWU to determine the acceptability and taste preference regarding new cottonseed protein products [52–55]. As a result of early research at TWU as well as at the Food Protein Research and Development Center at Texas A&M University, many ways to incorporate glandless cottonseed kernels into everyday food have been investigated. The kernels can be used in various forms: roasted, made into crumbs, boiled, ground, or served as a butter. Cookbooks published by TWU and Texas A&M include tasty recipes for appetizers, salads, main dishes, vegetables, breads, desserts, and sweets [56–57]. A taste test by elderly people comparing wheat flour to a wheat/cottonseed flour was favorable, indicating that fortification of a wheat flour with cottonseed flour could be used at health care facilities to increase nutritional value [58].

The use of cottonseed protein has several advantages in the food processing

arena. Cottonseed has more than four times the protein than whole wheat protein, has a low spoilage rate, and is economical [59]. Furthermore, cottonseed's bland flavor does not mask other foods, and its chemical composition and light color are characteristics which are conducive to use in the formulation of foods with enhanced nutritive value [60].

There are many cottonseed products which are either on the market today or in the development stage. Successful cottonseed products include cookies, doughnuts, cakes, breads, protein energy bars, high protein drinks, and gourmet coffee. Research using cottonseed concentrate in doughnuts has resulted in a moist product with no off-flavor and a rich yellow color. In addition, cookies have successfully been developed in which 12–20% of the wheat flour has been replaced with cottonseed flour or concentrate giving a more nutritious final product [60]. Snack foods, baked goods and candy have been prepared using a tasty, nut-like product from toasted or roasted glandless cottonseed kernels [61]. Roasted glandless cottonseed kernels have also been successfully used to prepare a high-protein nut-like snack called 'Tamunut'. Possible uses of this product include its inclusion in bakery goods, ice creams, and noncooked candies [62].

Recent research has shown that cottonseed flour can be successfully used to produce extrusion-cooked corn puffs [63]. Corn puff snacks with a medium concentration of cottonseed flour were rated equal to snacks that were all corn for sensory traits (flavor, texture, appearance). Glandless cottonseed has also been used as a high protein ingredient in low-salt plantain chips, chewy granola bars, oatmeal cookies and brownies.

Glandless cottonseed and regular (glanded) cottonseed are increasingly being used as protein sources for humans, as well as pets and livestock [59]. Kittens grew at an acceptable rate when glandless cottonseed provided approximately one-third of the dietary protein. Kittens preferred the cottonseed diet over a soy diet. New research also indicates regular cottonseed can also be used as a protein supplement for nursing calves. Nursing calves whose diet is supplemented with regular cottonseed had a higher daily weight gain than animals fed.

Many studies substantiate the role of high-protein cottonseed as a wholesome, nutritious, and versatile ingredient in animal, as well as human, food products. Research is on-going to produce and market new edible cottonseed products to combat the ever increasing need for optimum nutrition in our changing world.

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