BUCKWHEAT: COMPOSITION, CHEMISTRY, AND PROCESSING

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I. INTRODUCTION

Buckwheat is a traditional food widely utilized throughout the world. Buckwheat contains some nutritionally beneficial components at high levels and may have many characteristics as a functional food. This chapter will describe various characteristics of buckwheat as an important and traditional food.

A. BUCKWHEAT VARIETIES

Buckwheat is an important crop in some regions of the world. Buckwheat belongs to the Polygonaceae family and is taxonomically distant from the Gramineae family to which cereals such as rice, wheat, and maize belong. However, buckwheat seed has chemical and utilization characteristics similar to cereal grains, and thus is usually classified as a cereal. It is often alternatively classified as a pseudocereal.

There are several varieties of buckwheat species (Nagatomo, 1984; Ohnishi, 1991a). There are two cultivated species of buckwheat for human consumption, i.e., common buckwheat (*Fagopyrum esculentum* Moench) and Tartary buckwheat (*F. tataricum* Gaertner). Diploid common buckwheat is the most popular available buckwheat. Tartary buckwheat, which has a bitter taste, is often called by a name meaning "bitter buckwheat" in Japan and China. Tartary buckwheat is cultivated in regions such as China (Lin *et al.*, 1998; Ikeda and Ikeda, 1999) and eastern Tibet (Tsuji *et al.*, 1999). There are also some varieties of wild buckwheat species. In such species, *Fagopyrum cymosum* Meissn, known by a name meaning "perennial buckwheat", has been utilized mainly as a herb.

As common buckwheat has the inherent property of self-incompatibility caused by heterostyly, cross-pollination is performed through intermediators such as wind and insects like the honey bee. Therefore, there is a trend to lose the homogeneity of the inheritance of common buckwheat. Breeding is generally not easy. In Japan, there have been some "varieties" of buckwheat such as "*Botan-Soba* var.", "*Hashikami-Wase* var.", "*Shinano No. 1* var.", and "*Sando-Soba* var." (Nagatomo, 1984; Hayashi, 1999). In recent years, varieties such as "*Kita-Wase-Soba* var." (Inuyama *et al.*, 1994) and "*Hitachi-Aki-Soba* var." (Nakagawa *et al.*, 1985), which have been developed through repeated individual selection and pedigree selection respectively, have become widely available. Other common buckwheats are "local varieties" which have long been cultivated in local regions. In addition to diploid common buckwheat, tetraploid common buckwheat varieties are also available. In Japan, two autotetraploid varieties, i.e., "*Miyazaki-Ootsubu* var." (Nagotomo, 1984) and "*Shinshu-Oosoba* var." (Ujihara *et al.*, 1977), which are induced from diploid common seeds by colchicine, are widely used (Japan Buckwheat Association, 2001). At present, the major seeds cultivated in Japan are "*Kita-Wase-Soba* var.", "*Hashikami-Wase* var.", "*Shinano No. 1*" var., "*Hitachi-Aki-Soba*", and many local varieties (Hayashi, 1999).

Buckwheat is mainly classified into three types with respect to harvesting season: summer type, autumn type, and middle type. This classification may be due to susceptibility to the daylength (Nagatomo, 1984). For example, *Kita-Wase-Soba* var. belongs to the summer type; *Miyazaki-Ootsubu* var, to the autumn type; and *Shinano No. 1* var., to the middle type.

In Europe, there are various kinds of buckwheat seed varieties (Kreft, I. *et al.*, 1999) such as Siva var., Petra var. and Darina var. (Slovenia), Villanders var. and Seis var. (South Tirol), and Bamby var. (Austria). In Canada, there are also different varieties. In Canada, breeding of buckwheat for the Japanese market has been performed since 1965 by, first, Agriculture Canada, then the Morden Institute and at present Kade Research Ltd (Hayashi, 1999). In these breeding programs, some varieties have been developed, e.g. Tokyo var., Mancan var., AC Manisoba var., Koban var., and Koto var. (Hayashi, 1999). Some of the names of these Canadian varieties have Japanese connotations, i.e. *Tokyo*, the capital city of Japan; *Manisoba*, for *soba* produced in Manitoba; *Koban*, old Japanese money; and *Koto*, a traditional Japanese musical instrument.

Buckwheat breeding has been extensively discussed (Kreft, 1998a). Inter-specific hybridization between the genus *Fagopyrum* has been attempted (Suvorova *et al.*, 1994; Hirose *et al.*, 1993; Campbell 1995; Woo *et al.*, 1999). In this connection, Ohnishi (1995) has found a new kind of *Fagopyrum* species with self-compatibility, *F. homotropicum* Ohnishi. Interspecific hybridization between *F. esculentum* and the self-compatible species has been attempted (Wang and Campbell, 1998).

Chloroplast DNA analysis in buckwheat species has shown that the DNA of *F. esculentum* is phylogenetically distant from those of *F. tataricum* and *F. cymosum* (Kishima *et al.*, 1995). Taxonomy of *Fagopyrum* species has been attempted based on morphology, isozymes and cDNA variability (Ohnishi and Matsuoka, 1996). Phylogenetic relationships among various buckwheats have been extensively studied (Tsuji and Ohnishi, 2001a, b; Yamane and Ohnishi, 2001). Evaluation of genetic variability among common buckwheat populations has shown that the dendrogram separates accessions into a European group and an Asian group (Kump and Javornik, 1996). Classification of various buckwheat cultivars with respect to nutritional properties such as protein content and rutin content has been attempted (Michalova, 1998).

The International Plant Genetic Resources Institute (IPGRI) has supported activities on buckwheat (*Fagopyrum* spp.) genetic resources (Zhou and Aroya, 1995).

B. BUCKWHEAT QUALITY

Increasing attention has been paid to which varieties (or local varieties) of buckwheat seed may have desirable quality characteristics. Various factors dictate the quality of buckwheat (Ikeda *et al.*, 2001a). These quality factors consist of seed yield, grain shape and its uniformity, milling properties, color of grain, flavor, safety, agricultural chemicals residues, allergy-relating properties, etc. Nutritional and sensory characteristics of buckwheat are, of course, important quality factors. The subject of which buckwheat varieties have high nutritional quality or sensory quality is a very interesting one. These quality factors are dependent on various conditions, i.e. production places, cultivation conditions, weather conditions, soil conditions, fertilizer conditions, harvesting conditions, drying conditions, storage conditions, milling conditions, etc. The Japanese Standards on Agricultural Products (JSAP) prescribe that buckwheat is classified into four groups, 1st grade, 2nd grade, 3rd grade and out-of-selection, with regard to three points, i.e. weight per constant volume of grain, uniformity of buckwheat grain and moisture content. In the domestic buckwheat production (24,000 t in 1999), approximately 2954 t of the grain was subjected to the test: the grain tested consisted of 17 t of 1st grade, 507 t of 2nd grade, 2394 t of 3rd grade and 35 t of out-of-selection (JBA, 2001). Apart from JSAP, buckwheat grain with black hull is a preferred type for Japanese markets but no scientific reason can be found for this.

Methodology evaluating the quality characteristics, especially nutritional and sensory characteristics, of buckwheat is still not established. Careful characterization of the above quality factors has not yet been performed. This research subject is one of the most important problems in buckwheat research.

C. CULTIVATION OF BUCKWHEAT WORLDWIDE

Buckwheat is grown in Japan, Korea, China, Nepal, Bhutan, India, Russia, Ukraine, Tajikistan, Kazakhstan, Lithuania, Estonia, Belarus, Moldova, Poland, Yugoslavia, Croatia, Slovenia, Austria, Italy, France, South Africa, Canada, USA, Brazil and some other countries (Kreft, 1997; Ikeda and Ikeda, 1999). The annual world production of buckwheat is about 2.5

million metric tons (FAO, 1998), but this figure does not include the production of some countries such as Australia, Argentina, etc. The major producing countries are P.R. China, Ukraine, Russia Fed., Brazil, Poland, USA, Japan, France, Kazakhstan and Canada (FAO, 1998). There are many articles and books introducing cultivation and utilization of buckwheat in various countries and in various regions: China (Lin, 1994); Korea (Choi *et al.*, 1995); Tasmania in Australia (Orr and Shiratori, 1995); Bhutan (Norbu, 1995; Ohnishi, 1992); Nepal (Baniya, 1990; Uprety, 1995); Tibet and Himalayas (Ohnishi, 1993a; Aroya *et al.*, 1995; Gohill *et al.*, 1983); Karakoram and Hindukush (Ohnishi, 1994); Kashmira (Tahir and Farooq, 1989); India (Narain, 1983); Bangladesh (Haque, 1995); Ukraine (Bochkareva, 1995); Russia (Fesenko and Martynenko, 1995); Europe (Kreft, 1994); Poland (Ruszkowski, 1983; Krol, 1986); Slovenia (Kreft, 1995; Ikeda and Ikeda, 1994); Croatia (Knezevic and Baketa, 1990); Germany (Opperer, 1985); Italy (Borghi 1995; Ikeda and Ikeda, 1997); Denmark (Christensen, 1989); USA and Canada (Pomeranz, 1983); and Japan (Nagatomo, 1984, Ikeda, 1997a; Hayashi, 1999).

A worldwide-peace project by Japan International Cooperation Agency, with the devoted cooperation of Prof. A. Ujihara, Professor Emeritus of Shinshu University, Japan, has been attempting to cultivate buckwheat as an alternative crop to opium poppy, cultivated to obtain opium, in the mountain region of Myanmar. The present author continues to offer knowledge about buckwheat utilization to this project.

D. CULTURE OF BUCKWHEAT UTILIZATION

De Candolle (AD 1883) has suggested that the birthplace of buckwheat may be near the north region of China or Siveria; this theory has been prevalent for about one hundred years or more. But the wild ancestor (*Fagopyrum esculentum* spp. *ancestrale* Ohnishi) of common buckwheat has been recently discovered in Yunnan province in China by Ohnishi (1991b), suggesting that the birthplace of common buckwheat may be the south region of China. The oldest description concerning buckwheat in China, and maybe in the world, is found in the beginning miscellanea of "Ch'imin Yaoshu" (Chinese Book of Husbandry) written in the 6th century (Chia Ssu-Hsie, 6th century), although there is a hypothesis that suggests that this beginning miscellanea may have been added later. Concening the description about buckwheat in China, there is another hypothesis arising from its description in "Shen Nong Shu", which was written in an earlier period (Lin, 1994; Ohnishi, 1991a). Carbonized buckwheat seed, which perhaps was grown in the 3rd century BC to the 2nd century BC, has been found in China (Ujihara, 1997). It is considered that buckwheat became a popular food in the middle period of the Tang period of China (618–907 AD). (Nagatomo, 1984; Ohnishi, 1991a). There is the famous poem written by the poet, Bai Juri (772–846 AD): "In the brilliant moonlight, buckwheat is flowering like snow".

It is thought that cultivated buckwheat spread to European countries from the 12th to 16th centuries (Nagatomo, 1984). For example, the oldest description concerning buckwheat growing in Slovenia is found from AD 1426 (Kreft *et al.*, 1999). In Europe as well as Asia, buckwheat has been a traditional, common food: descriptions and drawings concerning buckwheat-eating habits and buckwheat cultivation can be seen in "Italienische Reise" (by J.W. von Goethe, Germany, AD 1786), the nursery tale "Eventyr og Historier" (by H.C. Andersen, Denmark, AD 1835–1875), the nursery tale "Kinder und Hausmärchen" (by J.u. W. Grimm, Germany, AD 1815), and the drawing "People who harvest buckwheat in summer" by J.-F. Millet (France, AD 1868), among others.

Diffusion of maize as a major crop from the New Continent to European countries such as Spain and Italy often contributed to the development of *pellagra* for people who consumed it. On the other hand, buckwheat has gradually been utilized as an acceptable food without contributing to any diseases, often as a duty-free food, in many European countries.

In Japan, the oldest description concerning buckwheat cultivation is found in the Emperor's edict concerning promotion of agriculture in the historical book "Shoku-Nihon-Gi" (AD 722). It is thought through analyzing historic relics that buckwheat cultivation in Japan may have begun at an earlier period (Nagatomo, 1984; Ujihara, 1997). As buckwheat characteristically has a short period from seeding to harvesting, and it can grow even in a nutrient-poor soil, buckwheat was often used as an alternative crop when other crops were poor. There are various literatures about buckwheat, e.g., the famous *haiku*-poem, "In Shinano [the old name of Nagano, a famous place for buckwheat cultivation], moonlight, lovely stone-Buddhist-images, and our buckwheat to boast". There are various places named in relation to buckwheat (*soba*), e.g. Mt Soba-tsubu (buckwheat grain), Soba Hara (field), etc. (Nagatomo, 1984). It has long been believed in Japan that buckwheat may be a beneficial food for human health, especially for prevention of some diseases such as hypertension. In fact, it appears that buckwheat may have many characteristics as a functional food, although there are still many unanswered areas relating to these.

The question of who firstly cultivated and ate buckwheat is an interesting problem. Ohnishi (1991a) suggests an interesting possibility that Yi people, the ethnic minority of China, described later, may be closely associated with the cultivation of buckwheat or the initial diffusion on buckwheat.

E. NAMES FOR BUCKWHEAT WORLDWIDE

Buckwheat is called by specific names in each country around the world (Kreft, 1998b; Ikeda and Ikeda, 1999). It is called *soba* in the Japanese language. In ancient times in Japan, there was a description (AD 931–936) that indicated that buckwheat was called *soba-mugi*, or *kuro-mugi* meaning black wheat. In the Chinese language, buckwheat is called *chao-mai* which is expressed by the same kanji-characters as *soba* in Japanese. In Korea, buckwheat is called "me-mil". In Myanmar, buckwheat is called "panjon" which means flower wheat. In India (Kashmir) buckwheat is called "trumba" (Gohil *et al.*, 1983). In Nepal, buckwheat is called "kuanna", which in Nepali means bad cereal (Baniya, 1990).

In European countries, there are various names for buckwheat (Kreft, 1998b; Kreft *et al.*, 1999). In the German language, buckwheat is called "Buchweizen". This expression is considered to mean a kind of wheat with seeds similar to the fruit of beech. "Buckwheat" in English has been firstly expressed as "beechwheat", originating from the German language and is considered to then be converted to "buckwheat" (Nagatomo, 1984). On the other hand, there is a more likely theory regarding the name for buckwheat in the German language, i.e. "Buchweizen" is originated from "Bockweizen" in old German (Marzell, 1951): "bock" in old German language means "unecht" (= "not true"). Therefore, "Buchweizen" means a wheat-like crop which is different from the true wheat. The word "buckwheat" in English also may have the same meaning as in the German language. There are some names that have a similar meaning in some European countries (Kreft, 1998b): "Boghvede" in Denmark, "Boekweit" in Holland, "Bouquette" in the Walloon language in Belgium, "Bovete" in Sweden, "Bucaille" in north France.

On the other hand, buckwheat is called "Ajda" in Slovenia (Kreft, 1998b). "Ajd" means "Pagan"; and thus "Ajda" means a cereal of Pagan. There are some expressions that have a similar meaning: "Heljda' in Croatia; "Heidekorn" in Austria and south Germany.

In Poland, buckwheat is called "Glyka" which means "cereals of Greek people" (Kreft, 1998b). This expression does not mean "cereals coming from Greece", but arises from the fact that Greek people, who were trading in some countries, were people from far away. That is, this expression means that buckwheat is a cereal from far away (Kreft, 1998b). There are some other expressions with a similar meaning: "Grechiha" in Russia, and "Grechka" in Ukraine (Kreft, 1998b).

On the other hand, buckwheat is called "Grano saraseno" in the Italian language, "Blé sarrasin" in French , and "Trigo sarraceno" in Spanish, which all mean "a kind of wheat diffused by Sarasen people"; essentially, that is, meaning a cereal from far away (Kreft, 1998b). In France it is also known as "Blê noir", which means black wheat.

F. MILLING AND THE KINDS OF BUCKWHEAT FLOUR

The fruit of buckwheat is botanically classified as an achene. Buckwheat achene includes one seed inside a coat. There is an achene coat and a seed coat in the buckwheat kernel. Buckwheat achene is usually dehulled prior to milling. The milling methods used are usually either roller milling, or the method of a traditional stone mill or its mechanized equivalent. As regards flour type, there are generally two milling methods: one is a method of thoroughtly milling the seed to obtain whole straight flour; the other is a method to separate various flour components. In the latter method, as the inner endosperm of buckwheat seed is easily ground into flour on milling, flour fractions are successively obtained from the inner layer to the outer layer: the first flour fraction (inner layer flour), the second flour fraction (middle layer flour), the third flour fraction (outer layer flour) and often the fourth flour fraction. The first flour fraction, which is abundant in starch, has a faint flavour and faint sweetness; the second flour fraction has a characteristic flavour and gives appropriate chewiness to the resultant products; and the third flour fraction is abundant in characteristic flavour, but the resultant products do not have good masticating properties. There is a wide variety of buckwheat products made using such flours.

II. COMPOSITION AND CHARACTERISTICS

A. GENERAL COMPOSITION

Buckwheat flour contains relatively high levels of several components such as protein, dietary fiber, some kinds of minerals, and some kinds of vitamins, as compared with other cereals such as rice and wheat. In general, buckwheat straight flour contains 12.0 g of protein, 3.1 g of lipid, 69.6 g of non-fibrous carbohydrate, 4.3 g of dietary fiber and 1.8 g of ash per 100 g flour; and buckwheat inner layer flour, 6.0 g of protein, 1.6 g of lipid, 77.6 g of non-fibrous carbohydrate, 1.8 g of dietary fiber, and 0.8 g of ash per 100 g flour (RCSTAJ, 2000). Although buckwheat flour is abundant in some nutrients such as protein, and some kinds of minerals and of vitamins, buckwheat flour contains relatively less amounts of some nutrients: it contains low levels of lipid, like many other cereals such as rice and wheat, and it contains no vitamin C. In view of nutrition, it may be important to ingest buckwheat products (e.g. noodles) together with other foods or dishes such as vitamin C-rich foods like purple laver, Welsh orion and *oroshi* (Japanese radish mash) (*oroshi-soba*) and lipid-rich foods such as *tempura* (deep-fried foods) (*tempura-soba*).

B. PROTEIN

Because of its high protein levels, buckwheat flour serves as an important source of dietary protein. The protein of buckwheat flour has a well-balanced amino acid composition with an amino acid score of 100 (based on FAO/WHO/UNU pattern (1985)) (RCSTAJ, 1986). Buckwheat protein has one of the highest amino acid scores of proteins of plant foodstuffs. Buckwheat flour contains high levels of albumin and globulin but low levels of prolamin and glutelin (Ikeda *et al.*, 1991a; Ikeda and Asami, 2000). Buckwheat flour may contain very little or no gluten. Immunological studies have shown little cross-reactivity between cereal prolamins and buckwheat proteins (Skerritt, 1986) and have shown that there is a very low level of gliadin-like polypeptide (Friis, 1988). Buckwheat therefore plays as important a role in the gluten-free diet for persons suffering from coeliac disease as bread and cereal do in the average person's diet (Kreft *et al.*, 1998).

On the other hand, the protein digestibility of buckwheat products is known to be relatively low in humans (RCSTAJ, 1982; Imaki *et al.*, 1990) and in animals (Farrell, 1978; Javornik *et al.*, 1981; Thacker *et al.*, 1983). We have analyzed endogenous factors affecting the protein digestibility of buckwheat flour. There are two major factors involved: one is the presence of antinutrients such as protease inhibitor and tannin (Ikeda *et al.*, 1986a, b, 1991a); and the other is the low susceptibility to proteolytic action of buckwheat protein *per se* (Ikeda *et al.*, 1991; Ikeda and Kishida, 1993). Thus we suggest that the protein digestibility of buckwheat products may be affected by these two factors. On the other hand, germination reduces protease inhibitory activity in buckwheat (Ikeda *et al.*, 1984). In this connection, seedlings and young plants of buckwheat are one of the available buckwheat foods (Nagatomo, 1984; Kreft, 1983). Protease inhibitory activity in buckwheat flour, however, is reduced only to a limited extent by heating (Ikeda, 1991).

Is low protein digestibility beneficial for human health or not? It is difficult to answer this. In fact, low protein digestibility may not be beneficial for infants or persons who have a weak digestion capacity. Ingestion of insufficiently cooked buckwheat products is known to lead to diarrhea. On the other hand, given that obesity is a current, major nutritional problem, it may not be necessary that all ingested food components be absorbed in the gastrointestinal tract. Furthermore, some beneficial effects on humans appears to occur from substances such as protease inhibitor and tannin. Apart from buckwheat, for example, it has been suggested that soybean trypsin inhibitor has a beneficial effect on diabetes mellitus through stimulation of the pancreas (Ookubo, 1992). In addition, current evidence suggests that polyphenols in plant foods, especially in red wine, have a beneficial effect on coronary heart disease, i.e. the French paradox (Renaud and de Lorgeril, 1992). Interest in "resistant proteins" in foods such as soybean is also increasing (Iwami, 1998). In fact, a possibility is suggested that buckwheat protein extract may have a beneficial effect on lipid metabolism (Kayashita *et al.*, 1996; Tomotake *et al.*, 2000); and this effect may be closely associated with low protein digestibility (Kayashita *et al.*, 1997). In addition, anti-oxidative activity among the polyphenolic compounds in buckwheat has been demonstrated (Watanabe *et al.*, 1995; Oomah and Mazza 1996; Watanabe, 1998; Ikeda *et al.*, 2001c).

The protein of buckwheat flour consists of many kinds of protein components (Ikeda *et al.*, 1995; Ikeda and Asami, 2000). Buckwheat protein consists of approximately 18.2% of albumin, 43.3% of globulin, 0.8% of prolamin, 22.7% of glutelin, and 5.0% of nitrogen residue (Javornik and Kreft, 1984). Studies on the proteins have been performed: characterization (Shibata *et al.*, 1979; Belozerskii and Dunaevskii, 1982; Dunaevskii and Belozerskii, 1989; Radovic *et al.*, 1996; Zhang *et al.*, 1998); electrophoretic analysis (Javornik and Kreft, 1984; Dolisek, 1980; Ikeda and Asami, 2000); amino acid analysis (Javornik *et al.*, 1981; Taira and Taira, 1964; Pomeranz and Robbins, 1972; Biely and Pomeranz, 1975; Pomeranz *et al.*, 1975) characterization of the 13S globulin (Belozerskii *et al.*, 1968; Dunaevskii *et al.*, 1991, 1993; Maksimovic *et al.*, 1996); characterization of albumin (Ono *et al.*, 1978); isolation and characterization of protein bodies (Elpidina *et al.*, 1990); comparison between diploid and tetraploid seeds (Belozerskii and Emtseva, 1970); immunological characterization (Shevchuk, 1983a; Skerritt, 1986; Friis, 1988; Fujino *et al.*, 2001); nutritional characterization (Sure, 1955; Furusawa and Harada, 1959; Farrell, 1978; Javornik *et al.*, 1981; Thacker *et al.*, 1983; Anderson and Bowland, 1984; Ikeda *et al.*, 1986a, b: Imaki *et al.*, 1990; Ikeda, 1992; Ikeda and Kishida, 1993; Ikeda, 1996a); and characterization in view of processing and cooking (Fornal *et al.*, 1981; Soda *et al.*, 1981; Ikeda *et al.*, 1991b).

Recently, we have shown with many buckwheat samples that protein content in buckwheat flour is negatively correlated to the starch content (Ikeda *et al.*, 1997). On the other hand, we have conducted a near-infrared diffuse reflectance spectroscopic analysis of components, including protein, in buckwheat flour (Hong *et al.*, 1996): multiple regression equations established between the second derivative NIR spectral data and the reference data give high multiple correlation coefficients for protein, starch and moisture.

Buckwheat contains various kinds of enzymes and enzyme inhibitors. Extensive studies have been performed on these components: proteases (Belozerskii *et al.*, 1973; Iordan and Belozerskii 1976; Emtseva *et al.*, 1977; Dunaevskii and Belozerskii, 1979; Dunaevskii *et al.*, 1983; Ikeda *et al.*, 1983; Belozerskii *et al.*, 1983; Voskoboinkova *et al.*, 1989; Dunaevskii and Belozerskii, 1990; Belozerskii *et al.*, 1990; Elpidina *et al.*, 1992); glucosidases (Takahashi and Shimomora, 1968a, b; Takahashi *et al.*, 1969; Kanaya *et al.*, 1978, 1979); lipase (Ohinata *et al.*, 1997); lipoxygenase (Henderson and Eskin, 1990); and enzyme inhibitors (Laporte and Tremolieres, 1962; Belozerskii, 1977; Ikeda and Kusano, 1978, 1983a; Pokrovsky *et al.*, 1978; Pokrovsky and Belozersky, 1980; Kiyohara and Iwasaki, 1985; Epidina *et al.*, 1991; Ikeda *et al.*, 1994; Gladysheva *et al.*, 1995; Belozerskii *et al.*, 1995, 1996; Dunaevskii *et al.*, 1996; Pandya *et al.*, 1996; Belozersky *et al.*, 2000). The relationships of these enzymes and enzyme inhibitors to the nutritional and functional properties of buckwheat and its products are a future subject of intense interest.

There is a problem concerning buckwheat protein, i.e. the proper nitrogen-to-protein conversion factor. This problem is a subject of controversy: four conversion factor values, 6.31 (RCSTAJ, 1966), 5.75 (Jones, 1931), 5.53 (Tkachuk, 1969), and 6.25 (non-specific conversion factor) have been long used by researchers. However, the exact conversion factor, i.e. 5.48, has been established (Yamaguchi, 1992).

C. CARBOHYDRATE

Buckwheat contains a high level of starch similar to various other cereal grains (Pomeranz, 1983; Furusawa and Kobayashi, 1962; Furusawa and Miyashita, 1964). Properties of buckwheat starch have been presented (Furusawa and Kobayashi, 1962; Furusawa and Miyashita, 1964; Kim *et al.*, 1977; Alekseeva *et al.*, 1979; Lorenz and Dilsaver, 1982; Soral-Smietana *et al.*, 1984; Fornal *et al.*, 1987; Smietana *et al.*, 1988; Qian *et al.*, 1998; Skrabanja *et al.*, 1998, 2001). Buckwheat starch granules are smaller as compared with wheat (Loranz and Dilsaver, 1982). Relationships between chain length distribution of amylopectin and gelatinization properties for sweet potato and buckwheat have been analyzed (Noda *et al.*, 1998). Generally, starch in cereal foods is considered to be associated with the palatability of the foods. However, the relationship of buckwheat starch to the palatability of buckwheat foods remains uncertain. This problem should be clarified in the near future.

Fagopyritol B1, *O*-α-D-galactopyranosyl-(1→2)-D-*chiro*-inositol, and related-compounds were studies in buckwheat (Horbowicz *et al.*, 1998; Steadman *et al.*, 2000, 2001a, b).

D. DIETARY FIBER

Buckwheat flour contains a high level of dietary fiber (Ikeda *et al.*, 1986b; Amarowicz and Fornal, 1987; Ikeda *et al.*, 2001b). A famous old book on traditional food in Japan (Honshyo-Shokkukan, AD 1697) suggests that buckwheat may have some beneficial effect on digestion and bowel movement; possibly the high levels of dietary fiber in buckwheat flour may be the reason for this. We have suggested that the dietary fiber in buckwheat flour may have binding capacity to materials such as peptides (Ikeda and Kusano, 1983b; Ikeda *et al.*, 1986a), which appears to be associated with the above beneficial effect. In this connection, studies on non-starch polysaccharides (Fujimaki *et al.*, 1969; Asano *et al.*, 1970; Ohinata *et al.*, 1991) in buckwheat are an interesting subject.

He *et al.* (1995) suggest in their study of an ethnic minority, i.e. the Yi people of China, that high buckwheat consumption may include low total and LDL serum cholesterol. They suggest that this beneficial effect of buckwheat may be due to the action of dietary fiber. On the other hand, we have had a chance to visit Xichang, China, where the majority of the Yi people live. We have learned that Yi people usually have chiefly Tartary buckwheat. The nutritional function of Tartary buckwheat may be much different from that of common buckwheat. Although the report of He *et al.* (1995) contains important information concerning the nutritional function of buckwheat, this report does not distinguish between Tartary buckwheat and common buckwheat. This interesting problem should be clarified in the future. On the other hand, interestingly, Bijlani *et al.* (1985) suggest that buckwheat has a beneficial effect on lipid metabolism and glucose tolerance.

The presence of resistant starch following autoclaving of buckwheat groats has been reported (Skrabanja and Kreft, 1998). It should be noted that the presence of slowly-digested or non-digested starch may have a nutritional effect similar to dietary fiber.

E. LIPIDS

Buckwheat flour contains a moderate level of lipid (Pomeranz, 1983; Mazza, 1988). Dehulled buckwheat seed contained from 2.6±0.2 to

3.2±0.1% total lipids of which 81–85% were neutral lipids, 8–11% phospholipids, and 3–5% glycolipids (Mazza, 1988). Dorrell (1971) has shown that the following eight fatty acids constituted an average of more than 93% of the total acids: palmitic, stearic, oleic, linoleic, linolenic, arachidic, behenic, and lignoceric acids. Properties of buckwheat lipids have been investigated including the effect of seeding time on lipid content and fatty acid composition (Taira *et al.*, 1986); lipid in buckwheat starch (Mano, 1977); changes on seed development (Horbowicz and Obendorf, 1992); lipase and free fatty acid changes on storage (Ohinata *et al.*, 1997); and sterol content (Tanaka *et al.*, 2001).

F. MINERALS

Twenty or more kinds of elements are known to be essential for humans. Interest in the nutritional function and bioavailability of essential minerals is growing. The research group of Dr Sayoko Ikeda has been extensively studying the minerals of buckwheat (Ikeda, S. *et al.* 1990, 1991; Ikeda, S. and Yamaguchi, 1993; Ikeda, S. and Shimizu, 1993; Ikeda, S. and Yamashita, 1994; Ikeda, S. *et al.*, 1995; Iikeda, S. *et al.*, 2000). Buckwheat flour contains magnesium, zinc, copper, and manganese at high levels (Pomeranz, 1983; Ikeda, S. *et al.* 1990, 1991; Ikeda, S. and Yamaguchi, 1993; Ikeda, S. and Shimizu, 1993; Ikeda, S. and Yamashita, 1994; Ikeda, S. *et al.*, 1995), and thus is a potential source of these minerals. For example, one dish of buckwheat noodles can supply about 10% of the recommended dietary allowance for zinc (Ikeda and Yamaguchi, 1993). Properties of soluble minerals released on enzymatic digestion has been presented (Ikeda, S. *et al.*, 1990; Ikeda and Shimizu, 1993; Ikeda, S. *et al.*, 2001).

In Japan, there is a traditional dietary custom of drinking the hot water left after soaking buckwheat noodles. Such a buckwheat soak (*soba-yu*) may be abundant in water-soluble components such as proteins, minerals, and vitamins as described later. Therefore, such a food habit may be fairly reasonable from the standpoint of nutritional science. On the other hand, it has been long said in Japan that buckwheat soak (*soba-yu*) exhibits beneficial effects on human health, whereas *udon* soak (*udon no yu*) obtained after soaking of wheat noodles (*udon*) does not exhibit any useful effect.

Buckwheat by-products, such as hull, stem and leaves, have characteristic profiles in mineral composition (Ikeda, S. *et al.*, 1999). On the other hand, there is a traditional, local method of preparing konjak with an aqueous extract of an ash obtained from burning the dried stems and leaves that are a by-product from harvesting buckwheat plants.

Recently, S. Ikeda *et al.* (1999) suggested that konjak preparation may be closely associated with potassium in the buckwheat ash extract.

The minerals in Chinese buckwheat varieties have been discussed (Wang *et al.*, 1995).

G. VITAMINS

Buckwheat flour contains various kinds of vitamins such as B_1, B_2, and niacin, at relatively high levels (Pomeranz, 1983; RCSTAJ, 2000). Thiamin-binding protein was isolated from buckwheat seed (Mitsunaga *et al.*, 1986) and some properties were shown (Rapala-Kozik and Kozik, 1992, 1996), but the bioavailability of thiamin from the protein remains uncertain.

It has long been believed that buckwheat may have a beneficial effect on the prevention of hypertension, but the detailed mechanism involved is still not fully clarified. In this connection, buckwheat contains a high level of rutin (Pomeranz, 1983; Shevchuk, 1983b; Kreft *et al.*, 1999; C.H. Park *et al.*, 2000). Rutin is a flavonol glucoside which is a vitamin-like substance having vitamin P (permeability) action, i.e. a beneficil effect on vascular disorders caused by fragile or permeable capillaries. Improvement of the rutin content in buckwheat by breeding has been attempted (Ohsawa and Tsutsumi, 1995). In addition, interest in inhibitors of angiotensin I converting enzyme for the prevention of hypertension is growing. Inhibitory activity against angiotensin I converting enzyme has been reported for a hydrolysate of buckwheat protein (Kawakami *et al.*, 1995). It is hoped that the reason responsible for the beneficial action which buckwheat may exhibit in the prevention of hypertension will be fully clarified.

H. ALLERGY

It is known that inhalation or ingestion of flour or products of buckwheat provokes severe allergic symptoms in sensitive persons (Wieslander, 1996). An accident happened in December 1988 in Japan, where a child died from an asthmatic episode provoked by intake of buckwheat in the feeding service lunch at an elementary school. Since then, buckwheat allergy has become one of the social problems in Japan. In Japan, buckwheat hull is frequently utilized in pillows. Buckwheat-sensitive persons often exhibit allergic reactions associated with exposure to buckwheat-hull pillows. Additionally, buckwheat hull is ofen incorporated as a food additive into processed foods such as cooked bread with powdered pepper, in which incorporation of buckwheat hull into the pepper is not stated on the food label. As a result, a buckwheat-sensitive person suffered from severe anaphylaxis by the presence of buckwheat hull in the cooked bread. Measurements of such food allergies are a major problem in Japan at present (The Asahi Newspaper, 4 September 1999). Recently, food labelling of five foods including buckwheat is legally obligated by The Japanese Government. A high frequency of buckwheat allergy is found in Japanese people; e.g. one report (Yokota, 1997) indicates that there are 194 cases (about 0.2% of frequency) of buckwheat allergy among 90,000 children in elementary schools. A high frequency of buckwheat allergy was also reported in other countries (Wieslander, 1996).

Studies on allergy to and allergen of buckwheat have been carried out extensively (Yanagihara, 1980; Yano *et al.*, 1989; Kondo *et al.*, 1993; Park and Nahm, 1996; Rout and Chrungoo, 1996; Park *et al.*, 1997; Nair and Adachi, 1998; Nair *et al.*, 1999; Wieslander *et al.*, 2000; Yoshimasu *et al.*, 2000; J.W. Park *et al.*, 2000; Chae *et al.*, 2001). In addition, Yokota (1997) suggests a possibility that the allergen responsible for buckwheat allergy may not be simply identified. Maat-Bleeker and Stapel (1998) reported that the radioallergosorbent test (RAST), a measure of IgE-binding, for buckwheat was inhibited by latex, suggesting that buckwheat and latex allergens may be cross-reactive. Astwood *et al.* (1996) reported that the allergens of plant-derived foods were often stable to digestion in a gastric model. Further characterization of buckwheat proteins and their role in allergy will be needed.

I. NUTRITIONAL FUNCTIONAL OF TARTARY BUCKWHEAT

A Chinese research group suggests that Tartary buckwheat may have beneficial effects on hyperlipidemia and hyperglycemia (Lin, 1994; Lu *et al.*, 1992; Lin *et al.*, 1998). In fact, many products such as noodles, pasta, tea, vinegar, spirits, tablets and so on are made from Tartary buckwheat. However, factors responsible for such beneficial effects remin uncertain. As described already, the nutritional function of Tartary buckwheat may be much different from that of common buckwheat. Some interesting studies have been conducted on Tartary buckwheat: cultivation (Tang and Zhao, 1995); protein (Kawakami *et al.*, 1994; Wang *et al.*, 2000); starch (Li *et al.*, 1997); an enzyme degrading rutin (Yasuda *et al.*, 1992; Ohara *et al.*, 1989); peroxidase (Zhang *et al.*, 1999); flavonoids (Sato *et al.*, 1980); and superoxide dismutase (Wang *et al.*, 1993). Further characterization of various components of Tartary buckwheat is needed to clarify the possible beneficial effects.

J. OTHER COMPONENTS AND RELATED STUDIES

Many other studies on buckwheat have been performed including: non-protein amino acids (Koyama *et al.*, 1971; Koyama and Sakamura, 1974);

polyphenols (Durkee, 1977; Ikeda *et al.*, 1991a; Luthar and Tisler, 1992; Luthar, 1992; Luthar and Kreft, 1999; Zadernowski *et al.*, 1992; Ikeda *et al.*, 2001c), antioxidative activities (Watanabe *et al.*, 1995, 1997; Watanabe 1998; Quettier *et al.*, 2000; Mukoda *et al.*, 2001); a scanning electron microscopic study (Pomeranz, 1972); inhibitory activity to glucose oxidase-peroxidase (Taniguchi *et al.*, 1975); dehulling (Mazza and Campbell, 1985); flavor (Aoki *et al.*, 1981; Yajima *et al.*, 1983; Aoki and Koizumi, 1986); color (Mazza, 1986; Ikeda *et al.*, 2001c); degradation of rutin (Ohara *et al.*, 1989); flavonoid metabolism (Margna *et al.*, 1985; Margna and Vainjarv, 1983); allozyme variability (Ohnishi, 1993b); enzymes (Vogeli-Lange *et al.*, 1989; Belunis and Hrazdina, 1988; Hrazdina *et al.*, 1991; Dovzhenko *et al.*, 1990; Mukhiya and Singh, 1982); plant-physiological properties (Namai and Fujita, 1995; Taranenko *et al.*, 1995; Samel *et al.*, 1996); metallothionein (Brkjacic *et al.*, 2000); milling fractions (Ikeda *et al.*, 1999; Steadman *et al.*, 2000, 2001b); morphology of the embryo (Kreft and Kreft, 2000); preparation of buckwheat juice (Baraniak and Bubicz, 1994); synthesis of alcohols with bio-catalysts (Nagaoka and Kayahara, 2000); effect on free radical generation and atherosclerosis (Wojciki *et al.*, 1995a); clinical effect of buckwheat herb tea (Archimowicz-Cyrylwska *et al.*, 1996; Ihme *et al.*, 1996); effect on atherosclerosis (Wojcicki *et al.*, 1995b); and effects in a renal ischemia-reperfusion system (Yokozawa *et al.*, 2001). Assessing a better harvest time for buckwheat was analyzed (Houtte *et al.*, 1995). The buckwheat plant (cv. Jianxi) was shown to exhibit aluminum resistance through accumulating oxalic acid in its root and leaves (Ma *et al.*, 1997). Azelaic acid and 3,4-dihydroxybenzoic acid in buckwheat hull were also studies (Cho *et al.*, 2000).

III. PROCESSING

A. NOODLE TECHNOLOGY

There is a great culture for noodles in Asia. The Chinese word "*mien*" originally means wheat flour, and the Chinese word "*bin*" originally means wheat products (Shu, 1989; Ishige, 1991; Okada, 1993). In later ages, *mien* came to have the meaning of some kinds of wheat products such as noodles in addition to meaning wheat flour. The Japanese word "*men*", which is expressed by the same kanji-characters as the Chinese word *mien*, means noodles. In Asian countries, traditional noodle-making techniques are generally classified into several categories such as hand-stretching technique, cutting technique and pushing-out technique (Shu, 1989; Okada, 1993; Ishige, 1991; Okumura *et al.*, 1990). It is thought that the birthplace of noodle-making techniques may be the north region of China and that their techniques have been widely diffused to various regions from there (Okada, 1993; Ishige, 1991; Okumura *et al.*, 1990).

The Chinese words *mien* and *bin*, and the Japanese word *men*, may resemble the Italian word *pasta*. *Mien*, *bin*, *men* and *pasta* equally mean products made mainly from wheat flour, often including other cereal flours such as buckwheat flour. On the other hand, there are differing opinions concerning the birthplace of pasta-making technology. The origin of pasta-making technology is the subject of much controversy.

There is a kind of pasta-like food made from buckwheat flour and often from wheat flour, called *mao-er-duo*, which means "cat-earlobe", in China. This product is prepared into a cat-earlobe-shaped food by hand. Interestingly, there is a kind of pasta called "*orecchiette*", which means earlobe, in Italy. In addition, there is another kind of pasta-like food made from buckwheat flour, called a word meaning *chaomai-ke* (Figure 1) which means "buckwheat shell'. Similarly, there is another kind of pasta in Italy, "*conchiglia*", which means shell. Such resemblance is very interesting in consideration of possible cultural interchange between Asia and Europe through the Silk Road. That is, such resemblance suggests that Asian food culture has long interchanged with European food culture by this route.

B. PROCESSING AND UTILIZATION OF BUCKWHEAT WORLDWIDE

Around the world, there is a large variety of buckwheat products (Ikeda, 1996b). Generally, dishes made from buckwheat seed are classified into two groups, flour dishes and groats dishes.

FIG. 1. *Chaomai-ke* (buckwheat shell) dish in Yulin, Shaanxi Prov., China. See Plate 4.

1. Japan

In Japan, about 126,000 metric tons of buckwheat are consumed (JBA, 2001). Domestic production is about 18,000 tons; the remainder is imported from various countries such as China, the USA and Canada. The import ratio of buckwheat grain to Japan consists of 85.0% from China, 7.9% from USA, 5.3% from Canada, and 1.8% from other countries such as Australia, New Zealand, Argentina, Russia and Myanmar etc. (JBA, 2001).

There are a variety of noodles in Japan, such as *udon* noodles, *somen* noodles and *ramen* noodles. Buckwheat noodles made from buckwheat flour-water dough are important in such noodles. Buckwheat noodles are the most popular product of various buckwheat products in Japan. Figure 2 shows a traditional buckwheat noodle dish called *zaru-soba* in Japan. The oldest description concerning buckwheat noodles is found from AD 1574. In Japan, buckwheat noodles are prepared by cutting thinly spread dough made from buckwheat flour and water. Therefore, buckwheat noodles are called *soba-kiri* in Japanese: *soba* means buckwheat; and *kiri* means cutting. Buckwheat noodles are also called *soba-men*. Subsequently, cut noodles are cooked in boiling water, removed from the water-soak, and washed in tap water.

There are various kinds of buckwheat noodles in Japan. For example, buckwheat noodles are prepared without any additives, or are often

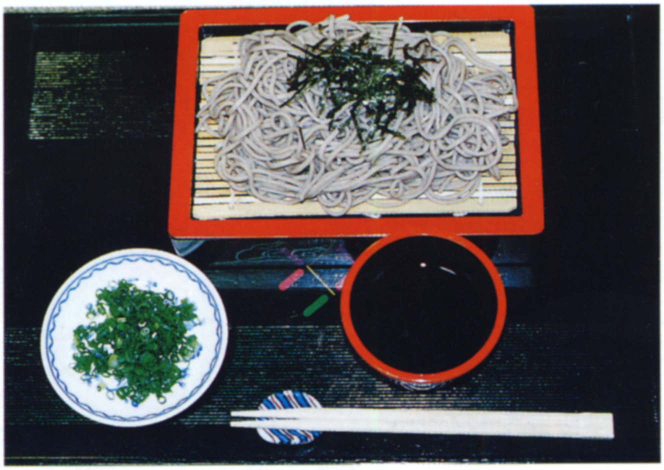

FIG. 2. Traditional buckwheat noodles dish (*Zaru-soba*) in Japan. *Zaru-soba* means buckwheat noodles on a bamboo plain basket (*zaru*). See Plate 5.

prepared with some binding-additives such as wheat flour, yam tuber and hen egg. Buckwheat noodles are also prepared from various kinds of flour fractions, e.g. with only inner layer flour alone or with whole flour. Such various buckwheat noodles are available in Japanese markets. Buckwheat noodles are generally classified into three types: raw noodles, dried noodles and instant noodles. Japan Agricultural Standards prescribe that buckwheat noodles should contain 30% or more of buckwheat flour. In Japan (1999), 68,000 tons of raw buckwheat noodles, 8,400 tons of freeze-dried buckwheat noodles, and 44,000 tons of dried buckwheat noodles are utilized (JBA, 2001).

There are many specialized restaurants (*soba-ya*) selling buckwheat noodles throughout Japan where people can enjoy palatable noodles prepared by *soba-men*-making experts. In rural regions, people usually eat hand-made noodles.

There is a prevailing, traditional practice of eating buckwheat noodles – New Year's Eve buckwheat noodle, *toshi-kishi-soba* (*toshi* means year; and *koshi*, passing) – on 31 December. In addition, there is another traditional custom of distributing buckwheat noodles – *hikkoshi-soba* (*hikkoshi* means moving house) – to new neighbors as a friendly greeting on moving into a new house.

Thus buckwheat noodles are one of the traditional and popular foods in Japan's food culture. In addition to noodles, there are various buckwheat products such as various kinds of cookies, bun with bean-gum filling, tea, spirit, groats with mushroom etc., that are common in Japan.

Buckwheat groats dishes are common in limited regions, such as Tokushima and Yamagata, of Japan. The limited utilization of buckwheat groats in Japan differs from that in Europe where buckwheat groats are widely utilized, as described later.

2. *China and other asian countries*

In China, the northern region mainly has the food-culture of *mien*, which is made from wheat flour and often made from other cereal flours such as buckwheat; and the southern region has mainly the food culture of rice (Shu, 1989). There are a large variety of buckwheat flour dishes in China, especially the northern region. As described already, there are *ma-er-duo* (cat-earlobe) and *chaomai-ke* (buckwheat shell) as traditional products. In addition to these buckwheat foods, there are a variety of other buckwheat foods. The procedure of noodle-making in China may be interestingly similar to the Japanese method. Noodles made from buckwheat flour-water dough are found in countries such as Japan, China, Bhutan and some European countries such as Italy and south Tyrol, etc. There is a thin-spread buckwheat flour-layer dish in China, resembling a buckwheat product *crepe* in France.

On the other hand, Tartary buckwheat is utilized in China, mainly by the Yi people in the south region (Xichang). In this region, there is a large variety of products made from Tartary buckwheat, such as noodles and spirits.

In Korea, there are various buckwheat foods such as *muk* and noodles. In other Asian countries such as Tibet and Bhutan, buckwheat is also widely utilized as a popular food.

3. Europe and Russia

Buckwheat is widely utilized in European countries. In Europe, there are two types of buckwheat foods: groats food and flour foods (Ikeda and Ikeda, 1999). Buckwheat is popular in Slovenia (Kreft, 1994; Ikeda and Ikeda, 1994). In Slovenia, there are various kinds of buckwheat products, such as a traditional food, *Zlevanka* (Ikeda and Ikeda, 1994).

Buckwheat groats are popular in Europe and Russia. Figure 3 shows a buckwheat groats dish in Slovenia. In Europe, cakes and bread are also popular foods made from buckwheat flour. In Italy, especially in northern Italy, there are various buckwheat dishes: buckwheat *polenta*; *sciat*, a dumpling dish; and a buckwheat flour dish. Buckwheat noodles or pasta,

FIG. 3. Buckwheat groats dish in Slovenia. See Plate 6.

which is called *pizoccheeri*, is popular in Italy (Figure 4). Buckwheat groats are popular in Europe and Russia. Interestingly, no groats dishes are found in Italy. In France, especially in Bretagne, buckwheat is a popular food, and there are some buckwheat flour foods such as *crepe* and *la galette de ble noir*. In Russia, *blini*, which is a buckwheat food similar to *crepe*, is utilized as a popular food (Ward, 1993). In some European countries such as France, there are beers made from buckwheat flour. In some European countries buckwheat tea is also available.

4. North America and other countries

Buckwheat is cultivated in North America, from where it is exported to other countries such as Japan. In Canada and the USA, there are various buckwheat products such as pancakes and groats, etc.

In Australia, buckwheat is also utilized. There is a pasta which is available as a gluten-free product. Recently, buckwheat (*Tasmania Soba*) has been cultivated in Tasmania, Australia, and is exported to Japan (Orr and Shiratori, 1995). As Tasmania is located in the opposite hemisphere to Japan, freshly harvested buckwheat seed can be obtained in the Japanese

FIG. 4. Buckwheat pasta dish (called *pizzoccheri*) in Italy. See Plate 7.

summer season when the freshness of buckwheat seed harvested in Japan decreases.

Today, buckwheat is thus widely cultivated and utilized around the world.

C. MOLECULAR BASIS FOR THE PALATABILITY OF BUCKWHEAT PRODUCTS

Much attention has been paid recently to the science of noodles and pasta, especially in relation to their palatability and acceptability (Kruger *et al.*, 1996). As described above, there is a large variety of buckwheat products globally. In view of their processing and cooking, interest in the palatability and acceptability of buckwheat products is growing. Buckwheat noodles are an important food in Japan and also in China. Buckwheat noodle dishes in Japan are relatively simple dishes, which consist mainly of just buckwheat noodles with soy-based soup. Therefore, much attention needs to be paid to the palatability and acceptability of buckwheat noodles. In Japan, excellent palatability and acceptabiliy are usually needed for buckwheat noodles made in various places such as homes, restaurants (*soba-ya*), food factories, etc. The principles behind the techniques of making buckwheat noodles need to be scientificaly clarified. In particular, it appears that mastication characteristics and flavour may serve as important factors affecting the palatability and acceptability of buckwheat noodles, and of course of other buckwheat products. Textural characteristics may be an important factor affecting the mastication characteristics of buckwheat produts. Although the textural characteristics of buckwheat products are considered to depend on the inherent characteristics of the components present, these factors remain unidentified.

Through his buckwheat research, the present author has recently proposed a new science for the 21s century, i.e. "*Molecular Cookery Science*" (Ikeda, 1997b). The palatability and acceptability of foods, including buckwheat foods, should be clarified from the standpoint of molecular cookery science in the coming 21st century.

We have attempted to clarify a molecular basis for the mechanical characteristics of buckwheat products. We have suggested that major components such as protein and starch may be important factors responsible for the textural characteristics, such as the hardness, springiness and chewiness, of buckwheat products (Ikeda *et al.*, 1997). We have succeeded in the preparation of twenty or more flour fractions form one buckwheat seed var. Our recent study (Ikeda *et al.*, 1999) of these many buckwheat flour fractions clearly confirmed a close relationship between endogenous protein and the textural characteristics of heated-buckwheat dough such as hardness, springiness and chewiness, as suggested by the previous study (Ikeda *et al.*, 1997). In addition, we have suggested that buckwheat noodles exhibit unique mechanical characteristics: relatively high tensile strength with low extensibility, high rupture energy and relatively high textural values including hardness and chewiness (Ikeda and Asami, 2000). These mechanical characteristics differ from those of wheat noodles (Ikeda and Asami, 2000). Furthermore, we have presented some mechanical characteristics of buckwheat products (Ikeda and Kishida, 1992; Ikeda *et al.*, 1992; Ikeda, 1996).

There is a common proverbial saying concerning the palatabiliy and acceptability of buckwheat noodles in Japan, i.e. buckwheat noodles prepared with all parts of the following four conditions are believed to be more palatable and acceptable: firstly, noodles made from just-harvested and dried buckwheat seed (*tori-tate*; *tori* means harvesting, and *tate* means after just-doing); secondly, noodles made from just-ground buckwheat flour (*hiki-tate*; *hiki* means grinding); thirdly, noodles made from just-prepared buckwheat noodles (*uchi-tate*; *uchi* means preparing); and lastly, just-cooked buckwheat noodles (*yude-tate*; *yude* means cooking). These four conditions are called *yon-tate* (*yon* means four), and often three conditions except tori-tate are called *san-tate* (*san* means three). It has been believed that buckwheat noodles prepared with *yon-tate* or *san-tate* are the most palatable. But, because of the dependence on importation for the majority of buckwheat grain consumed, large industrial-scale milling, and large industrial-scale prepariation and cooking, many people do not have a chance to eat such palatable buckwheat noodles prepared with *yon-tate* or *san-tate*. In old times, New Year's Eve buckwheat noodles appeared to be highly palatable and acceptable, prepared with *yon-tate*. In particular, the above *san-tate* and *yon-tate* are important for raw noodles. On the other hand, although Japanese people have long believed that buckwheat noodles prepared with *yon-tate* or *san-tate* to be much more palatable, the scientific reason involved remains largely uncertain. In general, buckwheat grain after harvesting is dried and usually is kept to about 15% moisture content. The dried buckwheat grain is usually stored at about 7°C under 60% to 70% relative humidity conditions. It is generally believed that buckwheat grain hervested in autumn may be stable up to about the rainy season (July) of the next year. As needed, stored buckwheat grain is milled by a milling company.

Concerning this interesting subject, we have tried to clarify changes in texture and components during the storage of buckwheat flour. We have shown that long-term storage of buckwheat flour alters the textural characteristics of buckwheat dough, and the alterations in texture may be associated with one of the components present such as protein (Ikeda *et al.*, 1998). Another report (Toyama *et al.*, 1982) showed increases in acid value and in reducing sugar content occurring on storage. Przybylski *et al.* (1995, 1998) reported that an increase occurred in off-flavor and free fatty acids on long-term storage of buckwheat grain. Further characterization of the changes during the storage of buckwheat grain and flour in view of *san-tate* and *yon-tate* will be a future, interesting subject. In addition, establishment of an improved system for transporting buckwheat grain without reducing its quality will be a future subject of research in view of the global utilization of buckwheat.

Recently, we have characterized buckwheat groats by mechanical and chemical analyses (Ikeda *et al.*, 2001c). Buckwheat groats exhibited unique mechanical characteristics as compared to other cereal foods such as japonica rice, indica rice and barley; and the color of buckwheat groats may be closely associated with the polyphenol present.

Concerning the palatability and acceptability of buckwheat products, there are many reports on: the mechanical properties of buckwheat products (Sugiyama and Fukuba, 1981a, b; Kondo *et al.*, 1982; Tsuji, 1984; Tsutsumi *et al.*, 1990; Nakano and Morioku, 1990; Yoshinaka *et al.*, 1990; Matsuhashi *et al.*, 1992); determination of blending ratio of wheat flour to buckwheat products (Imai and Shibata, 1978; Ohara *et al.*, 1989); technical characteristics of buckwheat bread and pasta (Bonafaccia and Kreft, 1994); and the effect of buckwheat protein on the rheological properties of maize starch (Bejosano and Corke, 1999).

Many unanswered areas remain concerning the palatability and acceptability of buckwheat products. Further characterization of buckwheat components in view of palatability and acceptability will be needed.

IV. BUCKWHEAT RESEARCH

Studies on buckwheat have been performed by many researchers in the world. The 1st International Symposium on Buckwheat was held in Ljubljana, Slovenia, 1980, proposed by Prof. Ivan Kreft. Then the International Buckwheat Research Association (IBRA) was organized. The 2nd International Symposium on Buckwheat was held in Miyazaki, Japan, 1983, which Prof. Takshi Nagatomo organized as the president. The International Symposium on Buckwheat has been conducted every three years: 3rd Symposium (by the president, Dr Marek Ruszkowski), Pulawy, Poland, 1986; 4th Symposium (by the president, Dr N.V. Fesenko), Orel, Russia, 1989; 5th Symposium (by the president, Prof. Lin

Rufa), Taiyuan, China, 1992; 6th Symposium (by the president, Prof. Toshiko Matano), Ina, Japan, 1995; and 7th Symposium (by the president, Dr Clayton Campbell), Winnipeg, Canada, 1998. The 8th Symposium was held in Chuchon, Korea in 2001. In the symposia, there has been active discussion concerning genetic resources, genetics, breeding, physiology, ecology, biochemistry, nutrition, food science, and so on, has occurred. The scientific, international journal on buckwheat, *fagopyrum*, is published by IBRA. Dr Ohmi Ohnishi, Kyoto University, Japan, is the editor-in-chief; Dr Kiyokazu Ikeda (the present author), Kobe Gakuin University, Japan, is the associate editor; and Dr Clayton Campbell, Canada, is the language editor. This international journal contains various scientific reports concerning buckwheat, i.e. breeding, genetics, processing, nutrition, medicine, cookery science, etc.

There are a number of unanswered questions concerning the nutritional and functional characteristics of buckwheat. The present author hopes that the present article may stimulate further investigation to fully answer them.

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