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FAGOPYRUM volume 40 (1), May 2023

# CONTENTS

## REVIEW



## RESEARCH PAPER



## SHORT REPORT

Fagopyrum 40 (1): 5-14 (2023)

Review

# A Current Review on Buckwheat: Historical Aspects of its Utilization in China and Japan, and Its Contribution to Human Nutrition

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## ABSTRACT

This paper was undertaken to review two following points regarding buckwheat: firstly historical aspects of its utilization in China and Japan; and secondly, its contribution to human nutrition.

## INTRODUCTION

Life-style diseases such as diabetes mellitus, dyslipidemia, heart diseases and hypertension, are a current, major nutritional problem globally. Prevention of these diseases is a research subject of much interest in nutrition science. Increasing attention on food constituents which may be effective for preventing such lifestyle diseases, is currently paid. The Ministry of Health, Labour and Welfare, Japan (MHLWJ, 2021) proposes that people will actively play a role at their social parts in 100-years old era. In relation to this, great interest is paid to the intakes of diets or foods with nearly perfect nutritional composition from the viewpoint of taking foods with well-balanced nutrients. Furthermore, food ingredients, if any, associated with longevity might be focused to the characterization of such food ingredients.

Buckwheat has been used in many countries for a long time (Ikeda 2002; Kreft et al., 2003). There is a variety of buckwheat foods produced on a global basis (Ikeda, 2002). However, there are unanswered subjects regarding the historical facts of utilization of buckwheat, especially in China and Japan.

Buckwheat food is rich in nutrition, and excellent in palatability. It is important to clarify nutritional characteristics of buckwheat. It is necessary not only to investigate the nutritional characteristics of buckwheat but also to elucidate factors responsible for its palatability.

This paper review two following points: firstly, historical facts of buckwheat utilization in China and Japan; and secondly, contribution of buckwheat to human nutrition including palatability.

## 1) HISTORY OF BUCKWHEAT UTILIZATION

### 1-1 History in China

It is known that China may be the birthplace of cultivation of buckwheat (Ohnishi, 2001 and 2003). Buckwheat (*Fagopyrum* spp.) spread to Europe and Russia via some roads such as the Silk Roads, and also spread to Korea and Japan. In prehistorical times in China, it has been thought that buckwheat plants existed as a spontaneous crop for many wild forests in some regions, such as Shandong, Guizhou and Yunnan provinces and the Sichuan heights in China. Buckwheat pollen was found in the sediments from about 5,000 years ago in Inner Mongolia Region.

The world-first Chinese anthology, "Shi-Ji" was written in the BC 11$^{th}$ century. It is estimated that this Chinese anthology may be comparable, as the worldwide oldest anthology, to "Iliad" and "Odyssea" which were written on BC 8$^{th}$ century by the famous Greek minstrel Homer. The anthology "Shi-Ji" describes that buckwheat was cultivated about 3500 years ago during the Yin dynasty (BC 17$^{th}$ century to BC 1046), which was the first dynasty of China. The book "Shi-Ji" also describes that "the Emperor Huang-Di" (BC 2510-2448), who first unified China, was often eating buckwheat noodles with porcine meats and mutton meats after heating.

Descriptions about buckwheat were found in another famous anthology written in the Zhou Dynasty (BC 256-1046). Zheng et al. (2003) described the importance of buckwheat utilization in "Qi-Min-Yao-Shu", edited on AD 532-549, which means complete agriculture works. In Japan, the famous agricultural book "Qi-Min-Yao-Shu" was widely utilized. At that time, there were many highly-educated intellectual Japanese people. They were able to understand many books written in Chinese language, such as the book "Qi-Min-Yao-Shu". They largely contributed to cultural exchanges with China. Buddhism, which happened in India and deeply affected Japanese culture later, was introduced to Japan in AD 552, through China.

It was reported that buckwheat was eaten as its noodles 4000 years ago in China. Carbonated buckwheat seeds, which were harvested in BC 2$^{nd}$ to 3$^{rd}$ century, are exhibited in Xian Archaeological Museum. The famous poet, Bai Juyi (AD 772-846), was born in Taiyuan, Shanxi Province. His famous poem is well-known in China and also Japan, i.e., "The moon is lightening in buckwheat field, and buckwheat flowers are blooming as like snowing" (AD 812) (Tenchi Em., 720). Then buckwheat foods, especially buckwheat noodles, become gradually popular in China.

There is an ethnic minority people called Yi people in China. They live mainly in Yunnan and Sichuan provinces. The minority peoples, who may begin the cultivation of buckwheat (Ohnishi, 2001 and 2003), have two different pictograms distinguishing between common buckwheat and Tartary buckwheat. Tartary buckwheat in particular is said to be very precious food to give to God of Yi people. Because Tartary buckwheat has a bitter taste (the bitterness comes from resolvent quercetin from rutin) for the word "Tartary buckwheat". As Tartary buckwheat have special implication, in China, Chinese people usually say ku-cho.

There is Mian culture in China and Japan, whereas there is Pasta culture in Europe including Italy. Mian in China and pasta in Europe are closely similar to each other. Both foods are made from cereal flour, including wheat flour and other cereal flour, such as buckwheat. In view of food cultural science, it is interesting that the form of each resultant product made from wheat flour are similar to each other. For example, orecchiette in Europe, including Italy and France, means earlobe, whereas ma-erdou in China means a pretty pasta such as cat's earlobe. For another example, conchiglie in Italy means a pasta like shell-shape, whereas Chao-mai-ke in China means a shell-shaped buckwheat pasta. Although each origin and birthplace of pasta and mian is very interesting, the detailed information remains an important subject of controversy.

In China, there is a folks saying "rice in south, whereas mian in north" (Zhou, 1988). This legend conveys that rice has been utilized in the southern region, whereas wheat, i.e., mian, has been utilized in the northern region. Mian originally meant wheat flour, whereas the word "bing" means products made from wheat flour (mian). Later mian wholly means wheat products and wheat products as the general term. Mian culture has been developed and established from the Tang Dynasty (AD 618-907) to the Song Dynasty (AD 960-1279) (Zhou, 1988; Okada, 1993).

The book entitled "Ethnobotany of Buckwheat" (ed. by Kreft et al.) was published in 2003. This book affords the history and various utilization of buckwheat in many countries. We hope that this book will be more and more completed in the future.

### 1-2 History in Japan

Buckwheat spread to Japan via some sea coast regions from Kyushu to Hokkaido (Ujihara, 2007) and Tsushima Island, Japan's coast regions via the Korean Peninsula (Ujihara and Matano, 1978).

Pollen analysis showed that the pollen of buckwheat flowers was found about 6600 years ago (Tsukada, 1976). Prof. Tsukada (New Yolk State Univ.) described that buckwheat pollen was found about 6600 years ago, but after that no pollen was found until AD 5$^{th}$ century. He suggested that buckwheat was cultivated by the slash-and-burn method from about BC 5$^{th}$ century to AD 5$^{th}$ century until pollen was not found during this period. Entering AD 5$^{th}$ century, large-scale farming of buckwheat was started (Tsukada, 1976). The oldest description of buckwheat in Japan was found on AD 744 (The 44 Emperor "Shoku-Nihon-Gi (Shoku (Sequel) Nihon (Japan) Gi (Record))". The famous Japanese encyclopedia "Wamyo-Ruiji-Sho" (ed. by Mr. Shitago Minamoto on AD 931-938), showed that buckwheat was already a popular food at that time.

Buckwheat noodles are a popular food in Japan (JBA, 2023). The first document recording that buckwheat was processed to noodles was found in AD 1572 (Niijima and Satsuma, 1985). Prof. Shigeo Miwa (Doshisya Univ.) described that the oldest discovery of a stone mill (Ishi-usu) was about AD 1220 in Japan. The Miwa's estimate on Ishi-usu (stone-mill) shows that the processing technology of buckwheat noodles may have been born after the discovery of Ish-usu in Japan, maybe at the beginning of 14$^{th}$ century. In this connection, several famous Priests such as Priest Dougen and Priest Yousai, who actively promoted Buddhism on the beginning of the 14$^{th}$ century, set up new Buddhism, i.e., Zen-shu, respectively. The Priests often visited China to learn on Chinese Buddhism. It is thought that they spread the processing technology of buckwheat noodles in China. The oldest buckwheat store, Owari-ya, was built in AD 1465 in Kyoto. This shop started with making of buckwheat confectionaries and later started making noodles. This description is written with the consent of the Owari-ya. The oldest document on buckwheat noodles was found in Jyosyou-ji Temple (Nagano-prf) document (AD 1574). The oldest book about the cookery procedure of buckwheat noodles was found "Ryori-Monogatari", which means cookery story (AD 1643). From around this time, buckwheat noodles may be popular foods in Japan. The utilization of buckwheat noodles is described later in subchapter (2-5) on beri-beri and buckwheat.

## 2) CONTRIBUTION OF BUCKWHEAT TO HUMAN NUTRITION

### 2-1 The major constituent, protein, in buckwheat flour, is characterized by high-content, well-balanced essential amino acids, resistant protein, gluten-free protein.

Buckwheat flour contains a high level of proteins: this flour has the highest protein among cereals usually used (STFCJ, 2020). Protein quality is generally judged from two points, i.e., amino acid score and digestibility. The amino acid score of buckwheat is 100, considered on

FAO/WHO/UNU amino acid standard (2007), meaning less or substantially no shortage on essential amino acid is found in buckwheat flour. On the other hand, buckwheat exhibits low protein digestibility in human (STFCJ, 1982). This finding suggests that buckwheat protein is a resistant protein, which exhibits resistance to gastrointestinal digestion. Comparison with other proteins showed that buckwheat protein belongs to resistant proteins with low digestibility (Ikeda and Kishida, 1993). Resistant proteins were reported with soybean (Azuma et al., 2000) and digestion after high amylose-corn starch (Morita et al., 1998). It is shown that consumption of buckwheat protein lowers plasma cholesterol and raises fecal neutral sterols in cholesterol-fed rats because of its lower digestibility (Kayashita et al., 1997), although there are many unanswered points. Furthermore, buckwheat contains no gluten, so buckwheat has characteristics of a gluten-free protein source.

### 2-2 Major constituent, available carbohydrate in buckwheat flour is characterized by low glycemic value and resistant starch.

Increasing attention is currently paid to glycemic index. Buckwheat noodles are known to exhibit a low glycemic index (GI) (Sugiyama, 2000). Buckwheat noodles exhibit approximately 56 of GI value, whereas polished rice, 100; and wheat bread, 92 (Sugiyama, 2000). On the other hand, buckwheat flour and groats contain highly digestion resistant starch compared to those of other plant foods (Kreft et al., 1996; Kreft et al., 2020). The observed low glycemic index may be closely associated with the high content of resistant starch and high dietary fiber described later.

### 2-3 Major constituent, unavailable carbohydrate, i.e., dietary fiber, is characterized by high content, high insoluble dietary fiber, possibly lowering effect on the onset of life-styled diseases.

Buckwheat flour contains dietary fiber at a high level (STFCJ, 2020). Meta-analysis (MHLWJ, 2020) showed that the intake of dietary fiber significantly exhibits negative correlations to the following eight items or diseases;

1) the total mortality;
2) the onset and mortality rate of myocardial infarction;
3) the onset of stroke;
4) the onset and mortality rate of circulatory diseases;
5) the onset of type 2 diabetes;
6) the onset of breast cancer;
7) the onset of stomach cancer; and
8) the onset of colorectal cancer.

Dietary fiber is an attractive ingredient that cures the above diseases and reduces total mortality. Buckwheat flour contains a higher level of dietary fiber compared with other cereals; buckwheat flour contains approximately 9 times more dietary fiber than polished rice and approximately 1.8 times more than wheat flour (STFCJ 2020). We showed that the major dietary fiber was present as insoluble form in buckwheat flour (Skrabanja et al., 2004). Dietary fiber in buckwheat flour meets approximately 25% of the daily needs of women aged 30 to 49 (MHLWJ 2020; STFCJ 2020). Buckwheat is an excellent source of dietary fiber.

On the other hand, Li et al. (2018) investigated, using random-effects models, relationship between buckwheat and cardiovascular disease risk: buckwheat intervened total cholesterol, triglyceride. These effects may be closely associated with dietary fiber.

### 2-4 Buckwheat flour is characterized by the presence in flour of various trace constituents, minerals, and vitamin.

Buckwheat flour contains various kinds of minerals and vitamins at high levels. It is known that 13 minerals are essential for humans (MHLWJ, 2020). Among the 13 minerals, buckwheat flour (100 g edible portion, 100EP abbreviated) (STFCJ, 2020) exhibited nutritional contribution (%) satisfy the required dietary reference intakes (MHLWJ, daily required nutritional intakes of 30 to 49 years old women or males, DRNI abbreviated) by 100 g buckwheat flour. Our estimation shows that buckwheat flour is important source of nine minerals, i.e., Mn (100, 100), Cu (77, 60), Mg (66, 51), P (50, 40), Cr (40, 40), Fe (27, 37), Mn (31, 27), Se (28, 23), and Zn(30, 22), in order of magnitude of nutritional contribution, as minerals with 20% or over of DRNI from 100EP (MHLWJ, 2020; STFCJ, 2020). The numbers in front in parentheses indicate % nutritional contribution to females 30-49 years old; and numbers in back, % nutritional contribution to males 30-49 years old.

Buckwheat flour also contains various kinds of vitamins in a high level. It is known that 13 vitamins are essential for humans (MHLWJ, 2020). In addition to minerals, our estimation shows that buckwheat flour is important source of six vitamins, i.e., niacin (64, 51), vitamin $B_1$(41, 33), biotin (34, 34), pantothenic acid

(31, 31), vitamin $B_6$ (27, 21) and folic acid (21, 21), in order of magnitude of nutritional contribution, as vitamins with 20% or over of DRNI from 100EP (MHLWJ, 2020; STFCJ, 2020). Numbers in front in parentheses indicate % nutritional contribution to females 30-49 years old; and numbers in back, % nutritional contribution to males 30-49 years old.

**2-5 Beri-beri and buckwheat.**

In relation to vitamin $B_1$, Japanese people have had rice as staple food since about 3,000 years ago after introducing rice from India, China etc. to Japan. Japanese people had rice as brown rice with bran. Since 420 years ago, Japan has stabilized given political and economic conditions. Many people, especially upper echelons, had white rice without bran. People who had white rice without bran got certain disease, called EDO (the old name of Tokyo)-WAZURAI (means disease). In Today's science, EDO-WAZURAI is beri-beri, which is caused by the deficiency of vitamin $B_1$. Beri-beri was once the main disease in Japan. Rice bran contains a high level of vitamin $B_1$, but white rice contains less or no vitamin $B_1$. The STFCJ 2020 shows that 100 g polished rice contains 0.02 mg of vitamin $B_1$; 100 g brown rice, 0.41 mg; and 100 g buckwheat flour, 0.46 mg. However, people with beriberi after leaving Edo (Tokyo), they went back to their country-side, where they had buckwheat etc, they cured beri-beri entirely in a few days. It was reported (Fujimaki, 1924) that many people gradually became aware of the curing effect of buckwheat against beri-beri. Today, Japanese people, especially people in Tokyo, like to eat buckwheat noodles. Tradition of healing from beri-beri may be the main reason why Japanese people, especially people in Tokyo, love buckwheat noodles. In this development, the concept 'vitamin' was established by the great scientists U. Suzuki, C. Funk, C. Eijkman and F.G. Hopkin (AD 1911-1929).

**2-6 Buckwheat and Buddhist practice: Can humans live only on buckwheat and some vegetable?**

The 2nd International Symposium on buckwheat was held at Miyazaki University, Japan in 1983. In the symposium, the great Buddhist C. Hagami (Enryaku-ji Temple in Mt. Hiei) had a lecture entitled "Buckwheat and Buddhist practice". Many people were deeply moved by his lecture.

Many Japanese people believe in Buddhism. In Japan there are various types of temples where Buddhist training practices for Buddhist are carried out. Among Buddhist training practices, there is famous Buddhist practice in Enryaku-ji Temples in Mt. Hiei where straddles between Kyoto and Shiga, The Buddhist practice is called "1000-day practice". The Buddhist practice are implemented over approximately 7 years. For 100 days after the 7 years-practice, person practicing does not eat five cereals, i.e., rice, wheat, millet, soybean and barnyard millet, they are as well without salt, fruits and sea vegetables for 100 days. Only two foods, i.e., buckwheat and some vegetable, are allowed for these 100 days. Can human live only on buckwheat and some vegetable?

Nutritional implications will be presented: buckwheat flour has a well-balanced amino acid composition comparable to eggs and beef meat. Buckwheat flour also contains a lot of starch which is an energy source. In view of vitamin nutrition, buckwheat flour contains various vitamins but except few vitamins, i.e., A, D, K, $B_{12}$ and C. Among the vitamins, A and C can be supplied from vegetables. Certain amount of vitamin D can be synthesized from 7-dehydro-cholesterol in human skin. Vitamins K and $B_{12}$ can be synthesized from micro-flora in our colon. There is no problem with vitamins in such nutrition. Therefore, we can conclude that humans can live by ingesting just buckwheat and vegetables. But, there is a possibility indicating that dietary life without salt and sea vegetables may lead to mild NaCl and iodine-deficiency. Interesting enough, thus, Japanese Buddhist Practice shows nutritional characteristics of buckwheat flour. Although buckwheat is not a perfect food, great interest is paid to buckwheat as a food with near-perfect ingredients for humans from the perspective of taking well-balanced nutrients.

**2-7 Polyphenols**

Common buckwheat flour contains 7 to 20 mg of rutin and approximately 1 mg of quercetin; Tartary buckwheat flour contains 1200 to 1500 mg rutin and approximately 100 mg quercetin, respectively (Asami et al., 2007).

Rutin, a flavonol-type flavonoid with rutinoside on 3'-position of B ring, is a representative polyphenol found in buckwheat. While flavonoid glycoside is generally deglycosylated in the small intestine by lactase-phlorizin hydrolase (LPH) or β-glucosidase, rutin is absorbed into the circulation slowly (Hollman et al., 1997; Crespy et al., 1999). This is because rutin is not substrate for LPH, and therefore it cannot be digested in the small intestine. Instead, rutin is hydrolyzed to quercetin aglycone by intestinal microflora in the large intestine. Part of quercetin aglycone is further converted into various phenolic acids, such as 3,4-dihydroxyphenylacteic acid (DOPAC), 3-hydroxyphenylacetic acid (OPAC) and vanillic acid, by intestinal microflora, and excreted in urine (Baba et al., 1983; Mullen et al., 2008; Makino et al., 2009). The rest is directly absorbed in the large intestine and entered enterohepatic circulation. The absorbed quercetin aglycone is then metabolized into various conjugates, such as glucuronides and sulfates, by phase II enzymes. In previous studies were detected quercetin-3-glucuronide, quercetin-3'-sulfate, and 3'-methyl-quercetin-3-glucuronide in human blood and lymph, and these metabolic conjugates circulate in the intestine, or are excreted in the bile and urine (Mullen et al., 2006; Murota et al., 2003).

Several studies have demonstrated biological effects of metabolites. It is reported that quercetin aglycone shows various biological activities, such as antioxidation, anti-inflammatory, anti-bacterial, anti-tumor, and anti-angiogenic activity (Yang et al., 2020; Kleemann et al., 2011; Park et al., 2008). Quercetin aglycone is completely metabolized to conjugates. Shimoi et al. (2000; 2001) reported that quercetin aglycone could exhibit various effects, such as antioxidant, anti-cancer and anti-inflammatory effects, at the inflammation site; it is probably because β-glucuronidase released from the inflammatory cells hydrolyze quercetin glucuronide into quercetin aglycone (Shimoi et al., 2000; Shimoi et al., 2001). So, it could show that quercetin aglycone has various effects on the inflammation site. We also showed that quercetin-3-glucuronide is passed through the endothelium to the smooth muscle cells (SMCs) at the time of inflammation (Mochizuki et al., 2004), and it exerted their antioxidant and cardiovascular diseases-preventing effect in the SMCs (Yoshizumi et al., 2002). Thus, rutin shows biological effects as quercetin aglycone or quercetin conjugates, when it is metabolized in organ as intestine and liver.

R. Lin and his group (1992) showed that Tartary buckwheat, but not common buckwheat, lowers blood sugars in patients suffering from diabetes mellitus and that Tatary buckwheat flour also lowers serum lipid in patients suffering from hyperlipidemia (Lin et al., 1992). However, the exact mechanisms responsible for the observed beneficial effects for diabetes mellitus and hyperlipidemia remain uncertain.

α-Glucosidase is a major enzyme responsible for the gastrointestinal digestion of saccharides into glucose. α-Glucosidase inhibitor is used as a drug curing diabetes mellitus. Although many factors are involved in preventing diabetes mellitus, α-glucosidase inhibitors in foods, if any, might inhibit the intestinal absorption of glucose, so maybe leading to the prevention of diabetes mellitus.

In this connection, increasing attention in polyphenols present in red wine and various plant foods is paid for beneficial effects on human health (Renaud and De Lorgeril, 1992). It is well known that buckwheat, especially Tartary buckwheat, contains a high level of polyphenols such as rutin and quercetin. It is hoped that polyphenols in common and Tartary buckwheat may have profoundly-beneficial effects on human health.

We have undertaken to identify α-glucosidase inhibitory activity in Tartary buckwheat given clarifying a factor responsible for the report by Lin's group showing that the intake of Tartary buckwheat lowered blood sugar of patients suffering diabetes mellitus (Ikeda et al., 2017).

Our finding showed that quercetin exhibited strong inhibitory activity against α-glucosidase. On the other hand, no inhibitory activity against this enzyme was found with rutin. α-Glucosidase is a major enzyme responsible for the gastrointestinal digestion of saccharides into glucose. α-Glucosidase inhibitor is used as a drug curing diabetes mellitus. Although many factors are involved in preventing diabetes mellitus, α-glucosidase inhibitors in foods, if any, might inhibit the intestinal absorption of glucose, which maybe lead to the prevention of diabetes mellitus. Our study suggests that quercetin may be an important factor responsible for the results reported by Lin's group showing that the intake of Tartary buckwheat lowered blood sugar of patients suffering diabetes mellitus. Further research should be performed for this interesting subject.

### 2-8 Mechanical characteristics of buckwheat products

Evidence has been accumulated that to enjoy food with high palatability may promote human health and longevity. In view of such evidence, increasing attention is being paid to these basic theories associated with the palatability of foods, from the perspective of their cooking and processing characteristics. However, there are still many unanswered questions on the palatability of buckwheat foods. Mechanical characteristics of buckwheat foods may be an important quality attribute affecting their palatability and acceptability (Ikeda, 2002). Hence, we have been trying to elucidate mechanical characteristics and the theory involved.

***2-8-1 Molecular cookery science***

"Molecular cookery science" has been proposed by K. Ikeda (1997). The new science will clarify food's palatability from a molecular basis. Textural characteristics, which are one of the mechanical characteristics of foods, are an important quality attribute for aspects of consumer acceptance and preference for foods. The science will be taken by our series of study (Ikeda et al., 1997) showed that endogenous protein and starch are responsible for textural characteristics of common buckwheat products. Furthermore, we showed to relationships of polyacrylamide gel electrophoretic-protein components to the mechanical characteristics of buckwheat dough using with many common buckwheat samples (Asami et al., 2008). The molecular cookery science will be taken over by scientists such as Yuya Asami and Mika Mochizuki.

A possibility showing that Tartary buckwheat may exhibit some beneficial effects on human health has been suggested (see 2-7; Lin et al., 1992). In Japan, various products, including noodles, made from Tartary buckwheat currently become popular.  We tried to analyze the effects of rutin on the textural characteristics of Tartary buckwheat dough (Asami et al., 2007). As rutin was incorporated into Tartary buckwheat dough, the hardness of the Tartary buckwheat dough was enhanced and the cohesiveness of the Tartary buckwheat dough was concomitantly decreased. This finding suggests that rutin may be an important factor affecting the textural characteristics of Tartary buckwheat dough.

***2-8-2 Scientific analysis of traditional preparation conditions of buckwheat noodles***

There are various traditional proverbial sayings about the palatability and acceptability of buckwheat noodles. In such proverbial phrases, 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; secondly, noodles made from just-ground buckwheat flour; thirdly, just-prepared buckwheat noodles; and lastly, just-boiled buckwheat noodles. In Japan it has been believed that buckwheat noodles made with all of the above four conditions may be the most palatable. In view of clarifying the above traditional proverbial saying, we analyzed mechanical changes in buckwheat noodles prepared under various conditions.

We tried to analyze the impact of storage to mechanical characteristics of noodles prepared from buckwheat grain stored under various conditions (Asami and Ikeda, 2005). Our chemical analysis showed a decrease in the breaking stress and energy of the resultant noodles prepared from stored buckwheat grain. These findings suggested that the temperature, relative humidity and the length of the storage period in the storage of buckwheat grain are important factors affecting the mechanical characteristics of its resultant noodles.

Another study (Asami et al., 2022) was performed to analyze the mechanical effects of leaving buckwheat noodles after their freshly making with or without subsequent cooking. After their freshly making and subsequent cooking, a remarkable reduction with time in breaking characteristics was found. The observed decrease in breaking stress and energy showed that the buckwheat noodles might be softened with the leaving time. On the other hand, our analysis showed that no brittleness was found in buckwheat noodles from the beginning until the early leaving time (within 1 min), whereas brittleness, which is unpalatable factor, appeared after leaving time of 2 min after subsequent cooking.

Our serious study on the mechanical characteristics of buckwheat products shows some scientific basis involved in traditional preparation conditions of buckwheat noodles.

**2-9 Dietary buckwheat enhances sirtuin without calorie restriction.**

Some recent reports show a relationship between buckwheat intake and sirtuin (Pande et al., 2020; 2022). Dietary buckwheat is reported to enhance sirtuin without calorie restriction (Pande et al., 2020). Although these reports are very interesting, further studies are needed. In Japan, the authors often asked opinions suggesting that people, handing at a milling companies or buckwheat farm, often live long lives. For the authors, there was no way to answer when there was no academic question. But, the reports by Pande et al. (2020; 2022) are very interesting, and we hope that the exact mechanism involved will be clarified in the future.

On the other hand, a recent report show that buckwheat and starch improve age-related dementia (Katayama et al., 2022). Clarification of the details of this mechanism will be expected.

There are many unanswered questions on buckwheat research. We hope these unanswered questions will be clarified fully for human health in the future.

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## IZVLEČEK

**Pregled o ajdi:** zgodovinski podatki o uporabi ajde v Kitajski in Japonski ter prispevek ajde k prehrani ljudi.

Prispevek obravnava dve tematiki. Prva je zgodovinski pregled pridelovanja ajde v Kitajski in Japonski. Drugi del je razprava o pomenu ajde v prehrani ljudi.

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Research paper

# Effects of planting density on branching habit in common and Tartary buckwheat

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## ABSTRACT

This study investigated the effects of planting density on the branching habit of common and Tartary buckwheat. A field experiment was conducted using a split-plot design with three replicates, comparing sparse (67 plants $m^{-2}$), moderate (111 plants $m^{-2}$), and dense (222 plants $m^{-2}$) planting densities in 'Kitawasesoba' (common) and 'Manten-Kirari' (Tartary) buckwheat varieties. Growth characteristics were examined at the stages of flower bud appearance, full flowering, and maturity. Results revealed that planting density had no significant effect on main stem length but showed significant effects on the number of branches in both species. As planting density increased, the number of branches decreased, with Tartary buckwheat exhibiting more significant changes in response to planting density than common buckwheat. The number of flower clusters on branches also decreased with increasing planting density. These findings suggest a potential role for branching plasticity in adapting to different planting densities while maintaining stable yields and indicate the importance of developing ideotypes with optimal branching habits for both species. This research contributes to a better understanding of buckwheat ideotypes and can contribute to future breeding efforts and crop management practices.

## INTRODUCTION

Two species of buckwheat are mainly used for food: common buckwheat (*Fagopyrum esculentum* Moench) and Tartary buckwheat (*F. tataricum* (L.) Gaertn.). Although common buckwheat is grown throughout the world, mainly in Russia and China, Tartary buckwheat production is primarily limited to China, Bhutan, and Nepal. Tartary buckwheat seeds contain rutin, a major polyphenol, at levels approximately 100 times higher than that found in common buckwheat seeds (Kitabayashi et al., 1995a, b). Consequently, both common and Tartary buckwheat have recently gained attention due to their potential health benefits (Kreft et al., 2020; Kasajima, 2021).

Although common buckwheat produces abundant flowers, its seed set is generally low due to self-incompatibility, resulting in poor seed yield (Woo et al., 2016). At present, the seed yield of common buckwheat in Japan is less than 1,000 kg $ha^{-1}$. In contrast, Tartary buckwheat is an autogamous plant with high fertilization efficiency, leading to higher seed yield than common buckwheat. However, pre-harvest shattering, aborting loss, and threshing caused by combine harvester lower the seed yield of both common and Tartary buckwheat (Funatsuki et al., 2000; Morishita and Suzuki, 2017). Additionally, Tartary buckwheat is more susceptible to excess soil moisture and salinity than common buckwheat (Matsuura et al., 2005a, b).

Buckwheat breeders have been developing varieties by improving plant type, including short plant height and determinate type, to increase yielding ability (Funatsuki et al., 1996; Honda et al., 2009; Morishita et al., 2013). Recently, a useful semi-dwarf common buckwheat line and a Tartary buckwheat cultivar with lodging resistance were developed (Shimizu et al., 2020; Morishita et al., 2015). In terms of cultivation technique, maintaining the ideal plant density through effective crop management is crucial for stabilizing seed yield (Donald, 1963). Planting density is a critical factor that affects the agronomic traits and yield of both common and Tartary buckwheat (Matsui et al., 1974; Xiang et al., 2016; Fang et al., 2018). Previous research on soybeans has shown that yield response at different planting densities is related to branch development, which is closely related to the ideotype of crops (Agudamu et al., 2016; Peng et al., 2008). However, an understanding of the effects of planting density on the branching habit in these species is limited.

The objective of the present study was to investigate the effect of planting density on the branching habit of common and Tartary buckwheat. This information will be useful for developing optimal crop management practices and ideotypes for these important food crops.

## MATERIALS AND METHODS

The present study used the leading buckwheat varieties in Hokkaido, Japan, namely 'Kitawasesoba' and 'Manten-Kirari' that were developed by the NARO Hokkaido Agricultural Research Center (Inuyama et al., 1994; Suzuki et al., 2014). The seeds of 'Kitawasesoba' were purchased from a commercial source. The cultivation was carried out in an unused field on a local farm, located in Yobito district, Abashiri, Hokkaido, which is the northernmost region of Japan, from June to September 2021. The field had peat soil with a slightly acidic texture (pH: 6.1). The study employed a split-plot design with three replicates, resulting in 18 subplots, where the main plots were assigned to two buckwheat species, namely, common buckwheat cv. 'Kitawasesoba' and Tartary buckwheat cv. 'Manten-Kirari.' The subplots were assigned to three planting densities, including sparse (67 plants $m^{-2}$), moderate (111 plants $m^{-2}$), and dense (222 plants $m^{-2}$) planting. Each subplot measured 4.8 $m^2$, consisting of four 4 m-long rows, spaced 1.2 m apart, and with a within-row spacing of 0.3 m. Border rows were excluded from any investigation. The seeds were planted using seeder tapes (Nippon Plant Seeder Co., Ltd.) at intervals of one every 5 cm (sparse planting), 3 cm (moderate planting), and 1.5 cm (dense planting). The seeding was conducted manually in rows on June 10, 2021. The fertilizer was applied only as a basal dressing for all plants, at the rate of 2 g $m^{-2}$ of N, 8 g $m^{-2}$ of $P_2O_5$, and 4.7 g $m^{-2}$ of $K_2O$.

The study investigated the main stem length and number of primary branches for 10 individuals of average growth from each plot at the stages of flower bud appearance and full flowering. The stage of flower bud appearance was defined as the day on which flower buds were observed in 40–50% of all plants. The stage of full flowering was defined as the day on which the apical inflorescence of the main stem bloomed in 40–50% of all plants. Owing to the differences in flower bud appearance and full flowering stages between common buckwheat and Tartary buckwheat, the investigation was conducted on an intermediate date, with respective investigations performed on July 12 and 23, 2021. Harvesting was conducted on September 3 and 6, 2021 for common and Tartary buckwheat, respectively. After harvesting, 10 individuals of average growth from each plot were collected, and their main stem length, number of primary branches, number of nodes on main stem, and number of flower clusters on the main stem and branch were measured. All small flower clusters were counted as one cluster. Subsequently, the plant samples were examined for seed yield after oven-drying at 80 °C for 48 h, and threshed. In this study, we only investigated the seed yield of Tartary buckwheat, as feeding damage by birds was observed in common buckwheat during the seed ripening period. Analysis of variance (ANOVA) was used to evaluate the effect of planting density on the growth and yield characteristics in the present study.

## RESULTS AND DISCUSSION

Tables 1 and 2 show the main stem length and number of branches in common and Tartary buckwheat grown under different planting densities at the stages of flower bud appearance and full flowering, respectively. In both cases, the main stem length was significantly longer in common buckwheat compared to Tartary buckwheat, with no significant difference between planting densities. Conversely, the number of branches showed significant differences between planting densities and between the two species (only at the stage of flower bud appearance) but no significant interaction between planting density and species was observed. As planting density increased from sparse to dense, the number of branches decreased for both common and Tartary buckwheat. These findings indicate that while planting density did not significantly impact the main stem length, it had a significant effect on the number of branches at the stage of flower bud appearance.

Table 3 shows the results of the main stem length and number of nodes and branches in common and Tartary buckwheat grown under different planting densities at the stage of maturity. The main stem length was significantly shorter in common buckwheat compared to Tartary buckwheat, but there was no significant difference between planting densities. The number of nodes on the main stem showed significant differences between planting densities and between the two species. The number of branches also showed significant differences between planting densities and between the two species. As the planting density increased from sparse to dense, the number of branches decreased from 3.87 to 1.73 for common buckwheat and from 7.00 to 4.27 for Tartary buckwheat. There was no significant interaction between planting density and species for both the length of the main stem and the number of nodes and branches. Results presented in Table 3 show that the main stem length of Tartary buckwheat was shorter than that of common buckwheat until flowering, but it became longer at maturity. This result is consistent

***Table 1.*** *Main stem length and number of branches in common and Tartary buckwheat grown under different planting densities at time of flower bud appearance.*

| Species | Planting density | Main stem length (cm) | Number of branches (/plant) |
|---|---|---|---|
| Common buckwheat | Sparse planting | 50.7 | 3.17 |
| | Moderate planting | 51.5 | 2.07 |
| | Dense planting | 48.8 | 0.87 |
| Tartary buckwheat | Sparse planting | 25.7 | 1.90 |
| | Moderate planting | 31.1 | 1.17 |
| | Dense planting | 32.0 | 0.13 |
| ANOVA | Planting density | ns | ** |
| | species | ** | ** |
| | Interaction | ns | ns |

** and ** represent significance at 5 and 1%, respectively. ns indicates not significant.*

***Table 2.*** *Main stem length and number of branches in common and Tartary buckwheat grown under different planting densities at time of full flowering.*

| Species | Planting density | Main stem length (cm) | Number of branches (/plant) |
|---|---|---|---|
| Common buckwheat | Sparse planting | 114.9 | 4.13 |
| | Moderate planting | 102.6 | 3.43 |
| | Dense planting | 104.2 | 1.93 |
| Tartary buckwheat | Sparse planting | 87.7 | 5.00 |
| | Moderate planting | 96.0 | 3.70 |
| | Dense planting | 92.3 | 2.30 |
| ANOVA | Planting density | ns | ** |
| | species | ** | ns |
| | Interaction | ns | ns |

** and ** represent significance at 5 and 1%, respectively. ns indicates not significant*

***Table 3.*** *Main stem length and number of nodes and branches in common and Tartary buckwheat grown under different planting densities at the stage of maturity.*

| Species | Planting density | Main stem length (cm) | Number of nodes on main stem (/plant) | Number of branches (/plant) |
|---|---|---|---|---|
| Common buckwheat | Sparse planting | 132.0 | 13.1 | 3.87 |
| | Moderate planting | 122.7 | 11.8 | 2.87 |
| | Dense planting | 120.6 | 11.9 | 1.73 |
| Tartary buckwheat | Sparse planting | 162.4 | 20.9 | 7.00 |
| | Moderate planting | 162.6 | 20.1 | 4.43 |
| | Dense planting | 152.7 | 18.8 | 4.27 |
| ANOVA | Planting density | ns | * | ** |
| | species | ** | ** | ** |
| | Interaction | ns | ns | ns |

** and ** represent significance at 5 and 1%, respectively. ns indicates not significant.*

with the reports by Kasajima et al. (2012) and Kasajima (2021). Furthermore, the extremely high number of branches (seven) in the sparsely planted Tartary buckwheat, compared to other planting densities, revealed that the effect of planting density was more significant in Tartary buckwheat than in common buckwheat.

Fig. 1 shows the numbers of flower clusters on the main stem and branches of each planting density in common and Tartary buckwheat. The number of flower clusters on both the main stem and branches tended to be lower in common buckwheat compared to Tartary buckwheat. Tartary buckwheat is an autogamous plant and has been noted to have a higher yield potential than common buckwheat because of the ease of its seed set (Kasajima et al., 2021). The large number of branches and flower clusters also suggests that these factors contribute to its high yield. Further research is needed to examine the high-yielding traits of Tartary buckwheat from a

***Table 4.*** *Seed yield in Tartary buckwheat grown under different planting densities.*

| Species | Planting density | Seed yield per plant (g/plant) | Seed yield per square meter (g/m$^2$) |
|---|---|---|---|
| Tartary buckwheat | Sparse planting | 1.79 | 120 |
| | Moderate planting | 0.93 | 104 |
| | Dense planting | 0.82 | 183 |
| ANOVA | | ns | ns |

*ns indicates that the differences among the planting densities are not significant (one-way ANOVA). The seed yield values per square meter were calculated based on the row and hill spacing for each planting density.*

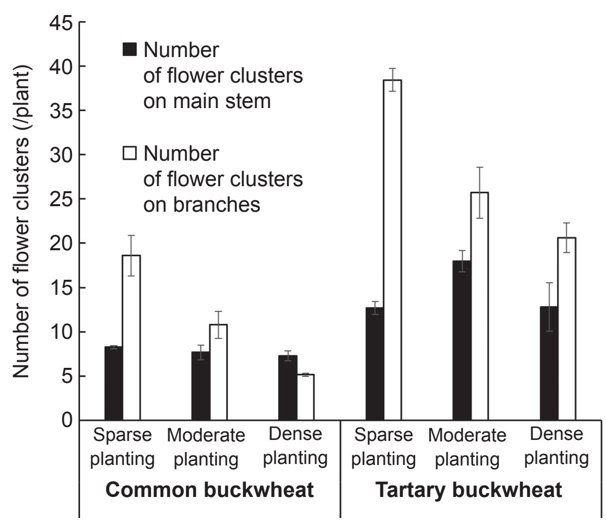
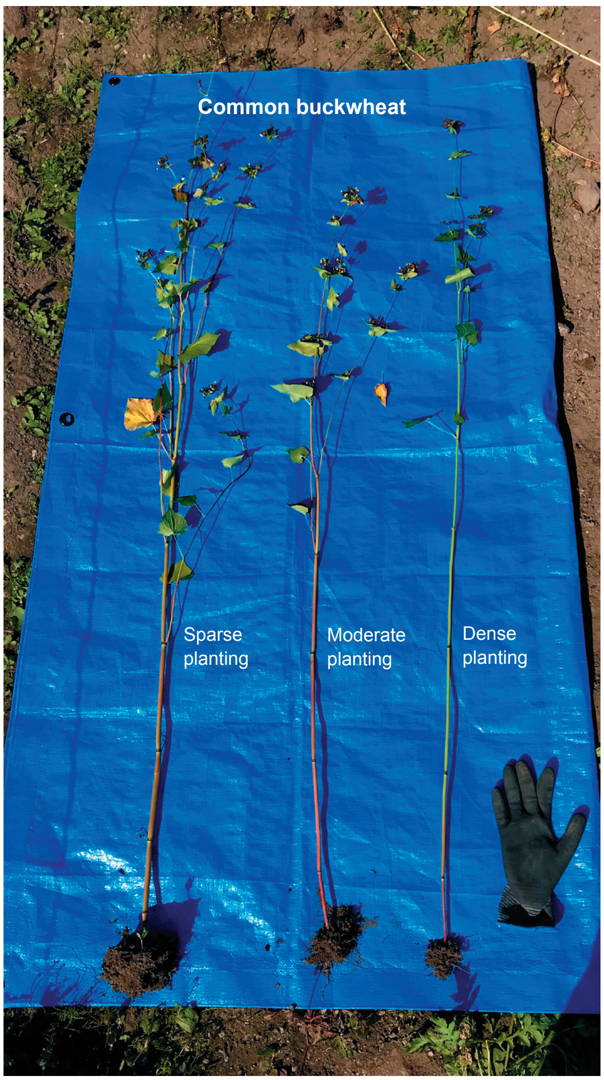



***Fig. 1.*** *Numbers of flower clusters on main stem and branches of each planting density in common and Tartary buckwheat. Vertical bars represent standard errors based on three replicates.*

plant type perspective. There were no considerable differences in the number of flower clusters on the main stem among planting densities in both common and Tartary buckwheat. However, the number of flower clusters on the branches decreased from 18.6 to 5.17 for common buckwheat and from 38.4 to 20.6 for Tartary buckwheat as the planting density increased from sparse to dense. Agudamu et al. (2016) defined branching plasticity in soybean as the ability to adapt to varying planting densities while maintaining a stable yield. This is achieved by controlling branch growth under dense planting conditions and promoting more branches under sparse planting conditions to compensate for the reduced main stem yield. In Tartary buckwheat, the seed yield per plant in sparse planting was higher than that of moderate and dense planting, although the seed yield per square meter was the highest in dense planting (Table 4). Branching plasticity may also play a role in the adaptation to different planting densities while maintaining stable yields in buckwheat as well. Further research is needed to explore the relationship between branching plasticity and yield stability in buckwheat cultivars.

Fig. 2 displays the harvested plants obtained from different planting densities of both common and Tartary buckwheat. Sparse planting conditions exhibited more branches and flower clusters compared to those grown under moderate and dense planting conditions, indicating a close relationship with the buckwheat ideotype. The numbers of flower clusters and bloomed florets are considered important factors that govern seed yield (Ujihara and Matano, 1975). Thus, the ideotype of buckwheat is considered a plant type with numerous branches and flower clusters; however, there has been limited research on this topic. In the past, plant types with many branches and flower clusters in buckwheat carried the risk of lodging. Nevertheless, with the introduction of semi-dwarf



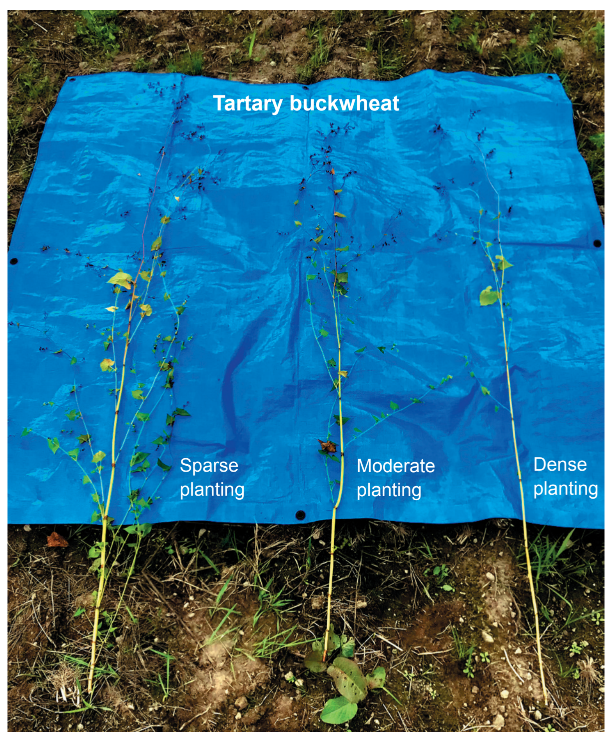




***Fig. 2.*** *Photograph of harvested plant of each planting density in common and Tartary buckwheat. Photograph of common buckwheat (left) on September 3, 2021. Photograph for Tartary buckwheat (right) on September 6, 2021.*

cultivars (Shimizu et al., 2020; Morishita et al., 2015), the risk of lodging is expected to decrease, and the need for research on plant types is likely to increase.

In conclusion, our study demonstrated the impact of planting density on the growth characteristics of common and Tartary buckwheat. The findings contribute to a better understanding of the ideal buckwheat plant type and the role of branching plasticity in adapting to various planting densities. This research has the potential to inform and support future breeding efforts and guide more efficient and sustainable buckwheat cultivation practices.

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## IZVLEČEK

**Vpliv gostote setve na razvejanje pri navadni in tatarski ajdi**

V raziskavi so proučevali učinke gostote setve na razvejanost navadne in tatarske ajde. Poljski poskus je bil izveden z uporabo razdeljene ploskve s tremi ponovitvami, pri čemer so primerjali redko (67 rastlin na $m^2$), zmerno (111 rastlin na $m^2$) in gosto (222 rastlin na $m^2$) gostoto setve pri ‚Kitawasesoba' ( navadna) in ‚Manten-Kirari' (tatarska) ajda. Rastne značilnosti so preverjali v fazah pojava cvetnih popkov, polnega cvetenja in zrelosti. Rezultati so pokazali, da gostota setve ni pomembno vplivala na dolžino glavnega stebla, vendar je pokazala pomembne učinke na število stranskih vej pri obeh vrstah. Z večanjem gostote setve se je število vej zmanjšalo, pri čemer je tatarska ajda pokazala pomembnejše spremembe glede na gostoto setve kot navadna ajda. Z večanjem gostote setve se je manjšalo tudi število socvetij na vejah. Te ugotovitve kažejo na potencialno vlogo plastičnosti razvejanja pri prilagajanju različnim gostotam setve ob ohranjanju stabilnih pridelkov in kažejo na pomen razvoja ideotipov z optimalnimi lastnostmi razvejanja za obe vrsti. Raziskava prispeva k boljšemu razumevanju ideotipov ajde in lahko prispeva k prihodnjim prizadevanjem za žlahtnjenje in način pridelovanja.

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**Short report**

# A Historical Review on the Oldest Documented Buckwheat Use in Korea

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## ABSTRACT

'Hyangyakgugeubbang' has been known as the oldest literature on buckwheat in Korea written in the time of King Gokong, old Korean dynasty. However, by 'Genesis of Koguryo dynasty' copied by Mr. Chang Hwa Park, it has been known that buckwheat has been used in Korea from Koguryo dynasty which was a former era of old Korean dynasty. Unfortunately, the original book of 'Genesis of Koguryo' has not been kept and thus historians have not approved the copied book as an official history book. Therefore, the oldest record on buckwheat use in Korea has not been recognized as the oldest book on buckwheat in Korea. So, Hyangyakgugeubbang' is still officially the oldest book on buckwheat in Korea.

Buckwheat was introduced from China to Korea in the time of King Gojong, Korean dynasty (1236~1251). In Asia, Korea is one of the oldest nation that buckwheat was traditionally used for food and folk medicine. 'Hyangyakgugeubbang' has been known as the oldest literature on buckwheat in Korea written in the time of King Gokong, old Korean dynasty. It is a widely accepted notion.

However, an another literature on buckwheat used in Korea was found, but it has not been approved as an official record. Based on the book titled 'Genesis of Koguryo dynasty' copied by Mr. Chang Hwa Park, it has been known that buckwheat has been used in Korea from the time of Koguryo dyanasty (B.C 37~668) which was a former era of old Korean dynasty (918~1392). The author of the 'Genesis of Koguryo' has not been known. The book was flowed out to Japan in the time of Japanese Empire (1910-1945) and was kept in the library of the royal family in Japan. Mr. Chang Hwa Park got the book from the library of Japanese royal family and copied it by hand writing and the copied book was transferred to Korea from Japan (Photo 1). Unfortunately, the original book of 'Genesis of Koguryo' has not been kept and thus historians have not approved the copied book as an official history document. Therefore, the oldest record on buckwheat use in Korea has not been recognized as the oldest book on buckwheat in Korea.

There are a few sentences on buckwheat in the Genesis of Koguryo. A record on 'Chumogyoung (named also as Jumong)' who was founder of Koguryo dynasty was described on the page 119 of the Genesis of Koguryo. A younger brother 'Eulgyoung' of queen 'Ryu' reported to the King Jumong that we have a lot of buckwheat but not have wheat

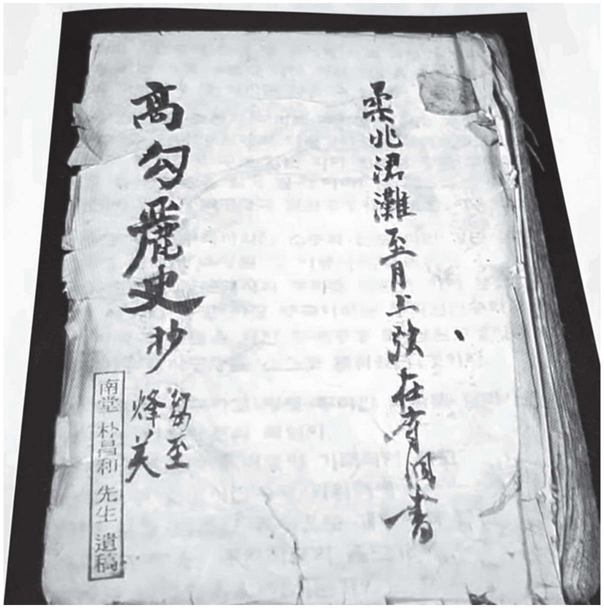


***Photo 1.*** *Genesis of Koguryo (Koguryo Sacho) copied by Mr. Chang Hwa Park*

or barley. The king said that buckwheat and wheat or barley were not the same because buckwheat was warm but wheat or barley were cool. On five cattle, seven grains, three liquors, and six fruits were written on a page 220 of the book. Seven grains were broomcorn millet, barnyard grass, millet, soybean, sorghum, buckwheat, and beefsteak plant (*Perilla frutescens*, family Lamiaceae). Such truth that there was buckwheat among the seven grains has a meaning that the Genesis of Koguryo was the oldest book on buckwheat in Korea. Moreover, the period that the Genesis of Koguryo was edited 1,200 years earlier than 'Hyangyakgugeubbang' that has been officially known as the oldest literature on buckwheat in Korea. However, the original book was not found elsewhere and copied book was not officially approved as a history document. So 'Hyangyakgugeubbang' is still the officially oldest book on buckwheat in Korea.

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## IZVLEČEK

**Zgodovinski podatek o najstarejšem dokumentiranem viru o uporabi ajde v Koreji**

"Hyangyakgugeubbang" je bil znan kot najstarejši pisan dokument o ajdi v Koreji, napisan je bil v času kralja Gokonga (1236~1251). Vendar je bilo znano, da so ajdo v Koreji uporabljali že prej, tudi v času dinastije Koguryo (leta 37~668 pr. n. št. ). Žal se izvirna knjiga 'Geneza Kogurya' ni ohranila, tako zgodovinarji niso mogli potrditi kasnejše kopije te knjige kot pravega uradnega zgodovinskega vira. Zato najstarejši zapis o uporabi ajde v Koreji ni bil prepoznan kot najstarejši vir o ajdi v Koreji. Tako je "Hyangyakgugeubbang" še vedno uradno najstarejši vir o pridelovanju in uporabi ajde v Koreji.