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The history and current state of flax (*Linum usitatissimum* L.) cultivation and use in Japan

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Abstract: Flax (*Linum usitatissimum* L.) is an ancient crop that has been cultivated for thousands of years for its fiber as well as for its oil rich seeds. The crop was introduced into Japan in the end of the 17th century, but its popularity did not begin to increase until the 1890s. The production of domestic fiber flax exceeded 45,000 metric tons in the late 1910s, and Japan had a well-developed linen industry for flax processing. In the 1960s, the mass production of synthetic fibers led to the collapse of Japanese linen industry, and consequently fiber flax culture in the country disappeared. In Japan, flaxseed oil with rapid drying property was once exclusively used for manufacturing a variety of industrial products such as paints, varnishes, linoleum, and printer's ink. Recently, this vegetable oil has gradually attracted the attention of Japanese consumers because of its health benefits mainly attributed to its high content of alpha-linolenic acid (omega-3 fatty acid). Over the past decade, the consumption of edible flaxseed oil has been increasing rapidly, but domestic oilseed flax production remains small. In this review, we describe the history of fiber flax cultivation in Japan. The current state, problems, and perspectives of oilseed flax culture and use in the country are also presented.

Key words: alpha-linolenic acid, cultivar development, cultivation history, cultural practices, fiber flax, germplasm, oilseed flax, omega-3 fatty acid

Zgodovina in trenutno stanje gojenja in uporabe navadnega lanu (*Linum usitatissimum* L.) na Japonskem

Izvleček: Navadni lan (*Linum usitatissimum* L.) je starodavna poljščina, ki se goji že tisočletja zaradi vlaken kot tudi zaradi na olju bogatih semen. Poljščina je bila uvedena na Japonsko proti koncu 17. stoletja, toda njena priljubljenost se je začela povečevati še le po 1890. Domača pridelava lanenih vlaken je v letu 1910 presegla 45.000 metričnih ton in Japonska je imela v tem času dobro razvito industrijo za predelavo lanu. V obdobju šestdesetih let (1960) je masovna proizvodna plastičnih vlaken povzročila propad industrije lanu na Japonskem, posledično se je izgubila tudi kultura gojenja lanu za vlakna v državi. Potem se je laneno olje na Japonskem , ki se hitro suši, skoraj izključno uporabljalo za izdelavo različnih industrijskih izdelkov kot so barve, laki, linolej in tiskarsko čenilo. V zadnjem času postaja to rastlinsko olje na Japonskem vse bolj priljubljeno pri potrošnikih zaradi zdravilnih lastnosti, ki jih v glavnem pripisujejo veliki vsebnosti alfa-linolenske kisline (omega-3 maščobne kisline). V zadnjih desetletjih se potrošnja jedilnega lanenega olja hitro povečuje, a pridelava ostaja majhna. V tem pregledu je opisana zgodovina pridelave lanu za vlakna na Japonskem. Prikazano je trenutno stanje, problemi in perspektive gojenja lanu za olje v deželi.

Ključne besede: alfa linolenska kislina, razvoj sort, zgodovina gojenja, načini gojenja, lan za vlakna, genetske osnove, lan za olje, omega-3 maščobne kisline

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1 INTRODUCTION

Flax (*Linum usitatissimum* L.) belongs to the Linaceae family. The crop may have originated in the Near-Middle East from where it spread to Europe, the Nile Valley, and over the rest of the world (Allaby et al., 2005; You et al., 2017). Flax is among the oldest crop plants: this crop has been cultivated for thousands of years for its fiber as well as for its oil rich seeds, and the ancient Egyptians already produced fabrics from flax fiber (Ehrensing, 2008; Jhala and Hall, 2010). In the Bible, flax or linen is mentioned many times, e.g., Exodus 9:31, the Book of Proverbs 31:13, and Jeremiah 13:1. For a long time, flax has been selected for production of either fiber or flaxseed (or often called linseed) oil. Consequently, the crop has diversified into two main types, namely, fiber flax and oilseed flax which are the same species but differ considerably in morphology, growth habits, and agronomic characteristics (Soto-Cerda et al., 2013). Fiber flax usually grows up to ca.120 cm tall and is scarcely branched. Oilseed flax is generally shorter, multiple branched, and produces more seeds. Its seed is larger, and higher in oil content than that of fiber flax (Fu et al., 2002).

Currently, oilseed flax is more economically important than fiber flax. Oilseed flax is grown mainly for seed oil, flaxseed meal, and flax straw (Ehrensing, 2008). According to the FAO statistics (FAO, 2023), global flaxseed production reached 3.34 million metric tons harvested from 4.14 million ha in 2021. Russia is the largest producer of flaxseed with 1.3 million tons, followed by Kazakhstan, Canada, China, India, Ethiopia, and France. What makes flaxseed so exceptional is the high alpha-linolenic acid (omega-3 fatty acid) content. Flax is well-known to be the richest botanical source of alpha-linolenic acid along with oilseed perilla [*Perilla frutescens* (L.) Britton var. *frutescens*] (Nakui and Mikami, 2023). Flaxseed oil with high amount of alpha-linolenic acid is highly susceptible to oxidation and polymerization. These properties make it suitable for various purposes in industry, including paint and flooring (linoleum) industries (Jhala and Hall, 2010; Hall et al., 2016). In addition to industrial applications, this omega-3-enriched vegetable oil has been used for human consumption (Čeh et al., 2020). Alpha-linolenic acid is believed to provide health benefits, because it is a potent inhibitor of pro-inflammatory mediators (Oomah, 2001; Jhala and Hall, 2010), and its adequate intake has been increasingly recommended. The positive human health impact is also attributed to high content of lignans, high-quality proteins, and dietary fiber; lignans are phenolic compounds that act as both antioxidants and phytoestrogens (Jhala and Hall, 2010; Bekhit et al., 2018).

Flaxseed oil has gradually attracted the attention of Japanese consumers because of its healthful properties (Nakano et al., 2009; Enokido and Ohashi, 2016). It is also worth mentioning that fiber flax was produced commercially in Japan until the mid-1960s. As far as we know, however, there is no scientific review regarding flax culture in the country. In this paper, we aim to summarize the history, current status, and perspectives of flax cultivation and use in Japan.

2 FIBER FLAX

2.1 CULTIVATION HISTORY

It is said that flax was introduced into Japan from China in the end of the 17th century, and grown for medicine (Hara, 1980). However, its cultivation did not spread until the latter half of the 19th century. In the 1870s, flax seeds were imported into Japan from the United States, Russia, and the United Kingdom, to grow flax plants on a trial basis in the northernmost island, Hokkaido (Hara, 1980). The results showed that the crop was well adapted to Hokkaido where the climate generally corresponds to Central European weather conditions. Around that time, a method used to separate fiber from flax stem was brought to Japan, and commercial flax production commenced in Hokkaido (Hara, 1980).

In 1900, a total of 11 domestic flax factories were in operation, and flax fibers obtained were used in manufacturing high-value linen products such as fine clothing, sheets, fire hoses, fishing nets, and canvas (Hara, 1980). Linen products were also requisite for military equipments including uniforms, tents, rope, and parachute harnesses. With the start of the Sino-Japanese War in 1894, domestic flax production actually grew rapidly; the

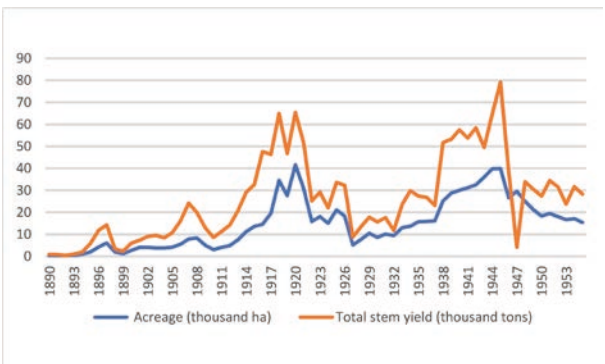

Figure 1: Production (total stem yield) and cultivation area of fiber flax from 1890 to 1955 in Japan. Source: The Commemorative Committee for the 70th Anniversary of Flax Business Development in Hokkaido (1957)

acreage under flax cultivation increased from 239 ha in 1891 to 4,275 ha in 1896 (Figure 1). The Russo-Japanese War broke out in 1904, which triggered a further rise in flax cultivation. In 1907, flax production amounted to 24,245 tons from an area of 7,918 ha (Figure 1).

During World War I, flax became a vital material in the production of a new weapon of warfare, viz., the airplane in Europe (Stamper, 2018). Linen was extensively utilized to cover wings and aircraft frames. A great amount of flax was inevitably needed to meet the demands of the linen and aviation industries. Japan exported flax fibers and linen products to Europe (Hara, 1980), and the total flax acreage in Japan increased by 4.4 times between 1907 and 1918 (Figure 1). Flax production reached 64,977 tons harvested from 34,530 ha in 1918. Following the war, the flax acreage dropped to 15,857 ha in 1922, chiefly due to the loss of military demand, and this decreasing tendency continued until 1937. Flax production peaked again during World War II (Figure 1).

Japan was defeated in the war in 1945. One third of the nation's wealth was destroyed, and food became extremely scarce. For a while after the war, the Japanese government gave priority to increasing food production (Moen, 1999), and consequently, flax growers reduced flax planting (Figure 1) and diverted more land under food crops such as rice, potato, soybean, and wheat. In the 1960s, the mass production of synthetic fibers led to a decline in the linen industry; flax culture in the country disappeared completely in 1967 (Hara, 1980).

2.2 CULTIVAR DEVELOPMENT

The establishment of the Japanese linen industry in the 1890s was solely dependent on imported flax cultivars or landraces, notably from France or Russia. The cultivation of these introductions increased year by year; however, within-cultivar variation in growth characteristics was viewed as problematic (Hara, 1980). In the late 1910s, the Hokkaido National Agricultural Experiment Station became significantly involved in flax breeding. The first domestic cultivar 'Pernau 1', a selection from a Russian landrace, was developed in 1923 (The Commemorative Committee for the 70th Anniversary of Flax Business Development in Hokkaido, 1957). 'Pernau 1' demonstrated high fiber quality and uniformity in growth characteristics though it was susceptible to flax rust and *Fusarium* wilt. This cultivar dominated domestic flax production for two decades from 1932 (Hara, 1980).

The next cultivars developed by the Hokkaido National Agricultural Experiment Station included 'Saginaw 1' (released in 1935) and 'Saginaw 2' (released in 1937), which were selected from the US cultivars 'Saginaw' and 'Washington 14', respectively (Hara, 1980). The release of these two cultivars provided the industry with high-yielding and disease-resistant flax, and both cultivars were widely grown for a decade from 1945 (Hara, 1980).

Attempts were also made to create high-yielding cultivars with better disease resistance and uniformity in growth, through controlled crossing. As a result, several prospective cultivars such as 'Unryu' (released in 1949) and 'Aoyagi' (released in 1955) were bred, but their fiber quality was not satisfactory (Hara, 1980). After 1957, the most popular cultivar was 'Wiera', which was introduced from the Netherlands and characterized by resistance to lodging and diseases as well as high fiber quality (Hara, 1980).

3 OILSEED FLAX FOR INDUSTRIAL USE

The seed oil of flax readily polymerizes upon exposure to air. As a result, it forms a soft and durable film (Jhala and Hall, 2010). This property is known as drying quality of flaxseed oil, and is responsible for extensive use in manufacturing various industrial products including paints, resins, varnishes, oilcloth, soap, linoleum, and printing inks.

At one time in Japan, flaxseed oil was exclusively utilized for industrial purpose. According to Kimoto (1963), 45,900 tons of flaxseed oil were used in 1962 to manufacture industrial products. About 30,000 tons of flaxseed oil were consumed for industrial applications annually in the 1990s (Saiwai Shobo, 2011); all the flaxseeds for oil extraction were imported from overseas. In the 2000s, however, the use of other vegetable oils (e.g., soybean oil) and petroleum products in place of flaxseed oil led to the considerable decline in flaxseed oil consumption for industrial purpose. The consumption reduced to less than 10,000 tons at the end of the 2000s, despite a general awareness of high quality of paints and coatings (varnishes) containing flaxseed oil (Saiwai Shobo, 2011).

4 FLAX FOR EDIBLE OIL

4.1 CONSUMPTION AND CULTIVATION

Both flaxseed and flaxseed oil had long been thought to be poisonous and were not used as a food source in Japan (Ono, 2009). Flaxseeds indeed contain anti-nutrients, particularly cyanogenic glycosides, which can be hydrolyzed to produce toxic hydrogen cyanide upon ingestion (Bekhit et al., 2018; Dzuvor, et al., 2018). Cyano-

genic glycosides occur in more than 2,500 plant species such as almond, wheat, barley, cassava, apples, and stone fruits (Cho et al., 2013), and the levels of cyanogenic glycosides in flaxseed (300-500 mg per 100 g of seeds: Singh et al., 2011) are considered too low to adversely affect the health of humans. Parikh et al. (2019) described that humans would need to consume the unrealistic amount of 1 kg of flaxseed daily for cyanide toxicity to ever manifests itself. We would also like to add that no adverse effect including food poisoning due to flaxseed consumption has been reported in the literature (Bekhit et al., 2018).

In the early 1990s, a small amount of flaxseed oil was first imported to Japan from North America with the aim of utilizing as a nutritional supplement (Ono, 2009). Recently, flaxseed oil has gained an established reputation as a high-value food ingredient thanks to healthful properties of this vegetable oil with high content of alpha-linolenic acid. Alpha-linolenic acid comprises ca. 63 % of the total fatty acids in the flaxseed oil available in Japan, whereas linoleic acid (omega-6 fatty acid) comprises ca. 16 % (Enokido and Ohashi, 2016). During the past decades, Japanese people have increased the Western diets which are characterized by a higher omega-6 and a lower omega-3 fatty acid intake (Tanaka et al., 2010; Simopoulos, 2010). A balanced ratio of omega-6/omega-3 fatty acids is thought to be important for human health (Simopoulos, 2010), and the Ministry of Health, Labour and Welfare, Japan recommends a ratio of 4 : 1 to 5 : 1 (MHLW, 2020). Consuming flaxseed oil is thus expected to improve omega-6/omega-3 ratio.

The domestic market of flaxseed oil for home use grew from US$ 34 million in 2016 to US$ 70 million in 2020; the market size of the total vegetable oils for home use in 2020 was estimated to be US$ 1,150 million (Nisshin Oillio, 2021). In the early 2000s, oilseed flax cultivation started in Hokkaido. On November 13, 2009, the Ministry of Health, Labour and Welfare, Japan announced the detection of transgene from an unapproved genetically-modified (GM) flax cultivar in a shipment of Canadian flaxseed exported to Japan (MHLW, 2009). The GM flax cultivar in question, FP967 (CDC Triffid), was not authorized for food or feed in Japan; it had tolerance to soil residues of sulfonylurea-based herbicides (Ludvíková and Griga, 2015). This incident led to rigorous and extensive testing guaranteeing the absence of GM seeds in imported flaxseed. In this context, it was hoped that oilseed flax plantings would increase in Japan (Kimura, 2017). The oilseed flax acreage, however, has remained below 50 ha for the last few years (JSAPA, 2021). There are several reasons why the plantings fail to increase, of which the most important one must be that domestic flaxseed is more than twice as expensive as imported flaxseed, owing to relatively low productivity of Japanese oilseed flax (see below).

4.2 CULTIVAR SELECTION

Nowadays, Japan's oilseed flax production consists mostly of the following three cultivars (JSAPA, 2021). Their agronomic characteristics are described below.

4.2.1 'Batsman'

It is an early maturing, mid tall, and high-yielding cultivar with average oil content. This brown-seeded cultivar was developed by Van de Bilt zaden en vlas, the Netherlands.

4.2.2 'Brighton'

A brown-seeded and mid tall cultivar bred by Van de Bilt zaden en vlas, the Netherlands. The cultivar is also characterized by average oil content and medium maturity.

4.2.3 'York'

A brown-seeded and medium /late maturing cultivar with good oil yield and oil quality. It has resistance to flax rust and *Fusarium* wilt. 'York' was developed at the North Dakota Agricultural Experiment Station in the United States.

4.3 CULTURAL PRACTICES

Oilseed flax requires moderate to cool temperatures during its growing season (You et al., 2017). It is also known that cool temperatures after flowering tend to increase oil (particularly linolenic acid) content (Čeh et al., 2020). Japanese oilseed flax is now cultivated exclusively in Hokkaido; temperatures in the main flax-producing areas range from 6 to 28°C during growing season (Japan Meteorological Agency, 2023).

Oilseed flax can be raised in almost all types of soils provided plenty of moisture is available, but it prefers well-drained silty loam, clay loam, and silty clays (Hall et al., 2016). In Japan, the crop is typically sown from the end of April through early June. The seed sowing depth should be around 2 cm for best germination. Seeding rate of 400-450 g per 100 m^2 is common in the country. Flax

competes poorly with weeds, so weed control is important during its early development. Weeds are controlled more easily by herbicides in the seedling stage and early treatment usually minimizes yield decreases. Oilseed-flax flowers generally bloom from mid-June to late July, each developing into a round seed capsule or boll. Ripening of the boll begins 20 to 25 days after flowering, and the boll contains eight or less small, smooth, and shiny seeds. The seeds should be harvested when a majority of the bolls turn brown. Edible oil is commonly extracted from flaxseed by mechanical cold pressing. Cold pressing has some advantages such as its capability of producing high-quality oil, low equipment cost and energy requirement, and avoidance of usage of chemicals, though the main drawback of this method is low oil yield when compared with solvent extraction method (Mikołajczak et al., 2023).

In Japan, it is recommended that oilseed flax be rotated with other crops (e.g., common buckwheat, wheat, and potato) to reduce disease potential and improve yields. Flax should not be grown in the same field more than once every three or four years. Few insect or disease pests affect oilseed flax in the country. Flax rust [caused by *Melampsora lini* (Ehrenb.) Desmaz.], *Fusarium* wilt [caused by *Fusarium oxysporum* f. sp. *lini* (Bolley) Snyder et Hansen], and anthracnose (caused by *Colletotrichum destructivum* O'Gara) can occur (NARO Genebank, 2023a). Insect pests such as army worm (*Spodoptera frugiperda* (Smith, 1797)) occasionally attack this crop, but seldom do significant damage.

5 CONCLUDING REMARKS

In Japan, several sources of vegetable oils are widely used for human food, but the market of vegetable oils for home use is practically dominated by canola, olive, and sesame oils (Nisshin Oillio, 2021). Over the past decade, the demand for flaxseed oil has been increasing as a result of its health benefits. Despite having much value, oilseed flax cultivation in the country has not received good research attention. It should also be pointed out that the average yield (455 kg ha^{-1} in 2019) of Japanese oilseed flax is surpassed by that in major oilseed-flax growing countries, viz., France (2,083 kg ha^{-1} in the same year), Canada (1,433 kg ha^{-1}), China (1,308 kg ha^{-1}), and the United States (1,243 kg ha^{-1}) (JSAPA, 2021; FAOSTAT, 2023). To make oilseed flax an attractive farm crop, there is a need to put more research and funds in the cultivar development and crop management practices for improving yield and on the value-added potential of this crop.

Germplasm is the basis of plant breeding programs, and enrichment of plant genetic resources is necessary to broaden the genetic base and invigorate breeding stocks (Diederichsen and Raney, 2006; You et al., 2017). Kiryluk and Kostecka (2020) mentioned that in Poland, the flax grain yield increased from 500 kg ha^{-1} in 1993 to as much as 1,500 kg ha^{-1} in 2016, due to the introduction of new cultivars and modern cultivation technologies. Unfortunately, the flax germplasm collections in Japan are currently limited (NARO Genebank, 2023b). Much effort is required to introduce new germplasm accessions and to evaluate the accessions for yield-relating characteristics such as seed mass and oil concentration in the seeds, as well as other agronomic traits. Additionally, cultural manipulations need to be improved in order to enhance the productivity of Japanese flax crop.

Historically, the straw residue from oilseed flax was considered a waste product, and burned or left in the field (Ehrensing, 2008). In recent years, attempts have been made to develop high-value products from oilseed-flax stems with applications in the pulp and paper, erosion control mats, reinforced plastic materials, and biofuel industries (Soto-Cerda et al., 2013). New industrial uses of oilseed-flax fiber will increase the demand for this multi-use oilseed crop.

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