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Derleme Makalesi / Review Article

Soybean (*Glycine max* L.) Sprouts: An Overview

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Abstract

In both human and animal nutrition, soybean is a significant source of fatty acids and protein. In the process of domestication of soybeans, the Chinese eventually learned that soybeans could be converted into a variety of soy foods, including tofu, soy sauce, soy paste, and soy sprouts to increase the flavour and digestibility of soy-based foods. Because of its excellent nutritional value and whole-year availability, soybean sprouts have become increasingly popular as a functional food. Sprouts are typically higher in phytochemicals that promote health compared to their mature relatives. The germination process of soybeans results in the accumulation of proteins, lipids, total phenolics, phytoestrogens, vitamins, isoflavones, and free amino acids. Additionally, soybean sprouts have elevated antioxidant phytochemical activity. Compared to dry seeds, soybean sprouts include more vitamins and minerals. In order to increase fatty acid compositions and generate high-quality soybean sprouts, a number of aspects, including seed size, sprout features, and health advantages, must be taken into account.

Keywords: Soybean sprouts, sprout, growth, yield, quality

1. Introduction

For the production of sprouts and for human consumption, crops like soybean [*Glycine max* (L.) Merr.], mungbean (*Vigna radiata*), and lucerne (*Medicago sativa*) are ideal. Alfalfa, lentil, and mung bean sprouts does not contain as much protein, fat, fibre, ash, calcium, or thiamine as soybean sprouts (Lee et al., 2015). Sprouts can be harvested and cooked within 5-7 days after their first germination and are a year-round vegetable option (Silva et al., 2013). On a dry weight basis, soybean seed typically contains 20% oil and 40% protein. Carbohydrates, vitamins, phytochemicals, minerals, and other minor constituents constitute the remaining 40% of the seed (Yang et al., 2015). Anabolic and catabolic processes, including the synthesis of enzymes and the repair of cellular components, are all part of the inherently complicated biological process of seed germination. These processes result in the production of new embryonic cells. Germination is an efficient technology for enhancing the nutritional and functional traits of soybean because it is a straightforward, low-cost procedure that can degrade antinutritional factors and trypsin inhibitors, accumulate bioactive phytochemicals like vitamins, phytosterols, and tocopherols, increase isoflavone content, and hydrolyze oligosaccharides (raffinose and stac). Additionally, during the germination phase, the amount and digestibility of soluble proteins are both increased (Bau et al., 2015). The soybean seed is made up of an exterior seed coat, two soybean cotyledons, and an embryo known as the germ. At one end of the hilum, under the seed coat, is the soy germ, from which a new plant sprouts and matures. Generally speaking, 95% of the entire soybean is made up of the cotyledon, 3% is made up of the seed coat, and 2% is made up of the soy germ. The nutrition and medical communities have recently learned that soy germ possesses a relatively larger concentration of bioactive substances than cotyledons, including isoflavones, soyasaponins, and tocopherols. Furthermore, to add value to soy germ, numerous research studies have been conducted to develop soy products with desired quality attributes for specific applications (Kim et al., 2013). Secondary metabolites are beneficial substances that help plants grow and develop but are not necessary for their survival. The content of secondary compounds frequently fluctuates significantly during germination. It is also known to decrease anti-nutritional factors, increase antioxidant effects, and subsequently increase the functionality of the seeds. Phenolic chemicals are secondary metabolites formed by plants as they grow. Simple phenols, phenolic acids, coumarins, flavonoids, stilbenes, hydrolysable and condensed tannins, lignans, and lignins are examples of plant phenolics. These substances may serve as phytoalexins, antifeedants, pollinator attractants, pigment-contributing substances, antioxidants, and defences against biotic and abiotic stressors. Soybean seeds contain many phenolic compounds such as chlorogenic acid, caffeic acid, ferulic acid, and p-coumaric acid (Koo et al., 2015). Isoflavones are bioactive phenolic substances that are widely distributed in some plant tissues. Isoflavones are structurally related to mammalian oestrogens and can bind to human oestrogen receptors in addition to their well-known antioxidant and antibacterial characteristics (Messina, 2016). Even though isoflavones are less active than animal oestrogens, exposure to high dietary quantities causes biological reactions in human. The research of isoflavones' health advantages and their potential as complementary therapies for a variety of hormone-dependent diseases, such as cancer, menopausal symptoms, cardiovascular disease, and osteoporosis, has been triggered by their remarkable bioactive traits (Ramdath et al., 2017). Among edible vegetables, soy is the only one that contains a high content of isoflavones, which are divided into four groups and 12 distinct forms: aglycones (daidzein, genistein and glycitein), β-glucosides (daidzin, genistin and glycitin), malonylglucosides (6″-O-malonyldaidzin, 6″-O-malonylgenistin and 6″-O-malonylglycitin) and acetylglucosides (6″-O-acetyldaidzin, 6″-O-acetylgenistin and 6″-O-acetylglycitin). In addition, the isoflavone content in soybean seeds may vary according to the cultivar and harvest year, the sowing date and growing location and the pathogen load in the soybean growing season (Junior and Ida, 2015). Despite these health advantages, the use of soybean as a dietary supplement has been restricted due to anti-nutritional soybean components as proteinase inhibitors, agglutinin, and soyatoxin. Different procedures, like as thermal treatment, fermentation, and germination, have historically been employed to eliminate anti-nutritional elements or lower their levels in soy diets. Even though sprouts have a high risk of microbial contamination due to their cultivation conditions (warm with high humidity), which are ideal for the growth of bacteria, such as *Salmonella*, *Listeria*, and *E. coli*, sprouting, stimulated by watering in the dark, is one of the cheapest and most effective methods for improving the nutritional quality of legumes and for reducing the level of anti-nutritional factors. There is an accumulation of free amino acids and soluble carbohydrates like sucrose, glucose, and myo-inositol during sprouting as a result of the breakdown of polysaccharides and proteins stored in the seeds into smaller components to provide energy and synthesise substrates for the early stages of seed germination (Gu et al., 2017). Many oriental people prefer various dishes like soymilk, soy sprouts, vegetable soybean, and soy paste served with rice. Among these, sprouts have long been a staple vegetable, particularly in regions where wintertime access to seasonal crops was limited (Yang et al. 2015).

2. Important factors related to soybean sprouts

The cotyledon and hypocotyl tissues of soybean sprouts have demonstrated several biochemical alterations during germination. During germination, sprouts often contained fluctuating amounts of phenolic chemicals, vitamin C, lipids, proteins, and amino acids (Lee et al., 2013). Because of the nutritional value and health advantages of soyfoods like tofu, soymilk, natto, bean sprouts, and edamame, there is a growing demand for these foods on the global market. Soybean seeds contain soluble sugars, primarily sucrose, stachyose, raffinose, and trace amounts of glucose and fructose (Wang et al., 2014). The antioxidant activity of soybean sprouts was evaluated by analysing phenolic chemicals, phytosterols, and fatty acids by Silva et al. (2013). After being exposed to ultrasound for different power levels ranging from 0 W to 300 W, soybean seeds were subsequently germinated for 5 days in the dark and chemically analysed by Yang et al. (2015). There were measurements made of the soybean sprouts' morphological changes, protein patterns, amino acid contents, gamma-aminobutyric acid (GABA) contents, IgE-binding, lipoxygenase isozyme activity, trypsin inhibitor, and isoflavone contents. Soybean sprouts' nutritional value and palatability were both enhanced by ultrasound treatment. In the study of Youn et al. (2011), it was discovered that the vitamin C and B levels varied amongst cultivars, demonstrating the significance of the soybean seed's chemical composition for the characteristics of soy sprouts. In a 7-day germination period with or without exposure to light, Shi et al. (2010) examined the isoflavone, phytosterol, tocopherol, mineral, protein, fat, and sugar contents of soybeans. Lee et al. (2013) investigated the metabolic changes of lutein, beta-carotene, and chlorophyll a during germination of the soybean sprout types.

In complete darkness, seeds were germinated at 20 °C with 80% humidity, and samples were taken every two days for ten days. Kang et al. (2012) assessed the amounts of β-carotene in soybean cultivars based on the size, application, colour of the seed coat and cotyledons, as well as the germination process. Koo et al. (2015) performed a proteomic investigation and observed sprout traits such as whole length, hypocotyl length, total protein content, total phenolic content, and antioxidant activity at a higher germination temperature (25 vs. 20 °C). Kim et al. (2014) examined the weight of 100 seeds, the ripening date, the tolerance to seed spot and root rot, the germination ratio, abnormal germination, hard seeds and the yield of sprouts. Gu et al. (2017) used gas chromatography-mass spectrometry (GC-MS) and liquid chromatography-MS (LC-MS) to analyse the metabolite profile of soybean sprouts at 0, 1, 2, 3, and 4 days after germination to better understand the connection between germination and nutritional quality. Chen and Chang (2015) used traditional targeted analysis technologies to partially explore the macromolecules and phytochemicals in soybean sprouts. In BRS 284 soybean sprouts, Junior and Ida (2015) assessed the profile of the contents of various soybean isoflavone forms as well as the impact of germination time on these compounds and the physical parameters. The sprouts from 168 hours of soybean seed germination were collected every 24 hours. The physical characteristics and isoflavone content of the seeds and soybean sprouts were assessed.

3. Protocols for evaluation of soybean sprouts

Since ancient times, soybean sprouts have been a crucial year-round food in Korea, China, and Japan. In Korea, soybean sprouts are used as a vegetable in soups, salads, and side dishes on an annual basis in excess of 500,000 tonnes. Small to medium-sized soybean cultivars, weighing 40–150 mg seed per plant, are used to make sprouts. They have strong seedling vigour and long, thick hypocotyls, which result in great sprout yield. Bright yellow cotyledons, silver-white hypocotyls, good sprout length (8–12 cm), and thick hypocotyls (2.0–2.2 mm) with good taste and texture are characteristics of good sprout cultivars. The procedure is as follows for assessing soybean for sprout characteristics: (1) selection of soybean lines with <150 mg seed–1 size and then soaking about 20 g of seed of each line in a vessel of water for 4 h at 20 C to initiate germination; (2) the vessels with soaked soybeans are transferred to a dark growth chamber or room with a controlled of temperature (20 C) and a relative humidity (RH) of 80% conducive to low-seedling disease and uniform germination; (3) seeds are watered several times a day, for four or more days; (4) sprout characteristics are then measured. Testing is started when seeds from different lines have been composited from a plant row in the F5 or later generations because the sprout trait testing technique is labor-intensive and requires a sufficient number of seeds. More than 150 seedlings must be germinated, which necessitates careful watering regimens spread out over many days and the transfer of seedlings from water baths to growth chambers. The number of entries that can be researched is limited by the space in water baths and growth chambers. When comparing soybean genotypes for sprout features using the conventional approach, sprouting over 150 seeds is equivalent to sprouting fewer seeds (10, 20 or 40) on an agar medium (Lee et al., 2007). Pungsannamulkong, a well-known sprout soybean, was grown on 1.0, 1.2, and 1.4% agar media, and its sprout growth properties were studied by Lee et al., (2007). Five days after 20 or 40 seeds were planted on a 1.4% agar medium, sprout features were extremely similar to those obtained using the conventional approach. To determine sprout characteristics, soaking seeds were not superior to dry seeds when germinated on the agar medium. The typical approach for determining the sprout characteristics for each cultivar was comparable to the evaluation of 20 dry seeds of eight well-known sprout cultivars on a 1.4% agar medium. Compared to the conventional method, the agar method uses less labour, fewer seeds, no watering schedules or water baths, and uses less growing chamber area. This makes it possible to assess additional lines from soybean breeding populations from earlier generations. The agar method will improve the efficiency for evaluating soybean breeding lines for sprout traits

4. Results of the selected studies

High concentrations of macro- and micro-elements like sodium, zinc, copper, potassium, iron, phosphorus, magnesium, and manganese can be found in soybean sprouts. Depending on the soybean variety, these components are distributed differently in the hypocotyls and cotyledons (Youn et al., 2011). According to Kim et al. (2013), soybean sprouts are a good source of both essential and non-essential amino acids. During sprouting, the soybean's oil content dropped from 15% to 10% (Shi et al., 2010). Vitamins A, B1, E, and C are known to be present in soybean seeds. Numerous studies have shown that sprouting considerably raises the amount of these vitamins in food (Youn et al., 2011). Vitamin C levels were found to be higher in hypocotyls than cotyledons (Youn et al., 2011). In whole sprouts of the soybean varieties Pungsannamul and Bosug, lutein and beta-carotene levels increased, according to Lee et al. (2013). In Pungsannamul and Bosug, respectively, they saw a rise in lutein levels of around 20, 24 fold and an increase in β-carotene levels of about 8, 17. In comparison to the 5-day-old sprouts, the average β-carotene content in soybean seed was 33.3 g/g (Kang et al., 2012). Due to their sweetness and ease of digestion, glucose, fructose, and sucrose are regarded as desirable sugars, but stachyose and raffinose are unfavourable sugars that are indigestible and induce gas and diarrhoea (Wang et al., 2014). During the sprouting phase, the soybean seed's sugar content reduced. According to Shi et al. (2010), the sugar content of soybean seeds was 19.9% at the time of sowing but dropped to 14% after 7 days of sprouting. Minerals essential for human nutrition, including Zn, Na, Fe, and Calcium, are found in soybean sprouts. These minerals are irregularly distributed between the cotyledons and hypocotyls in sprouts (Youn et al., 2011). The type of raw component soybeans, cultivating temperature, cultivating water temperature, overhead flooding method, water quality, etc. are the main determinants of the amount and quality of soybean sprouts. Soybean sprouts cultivated with groundwater from the "Jeonju region" by Lee, (2015) resulted in a sweeter taste and a more delicious and crunchier texture. It also resulted in a less undesirable ‘beany’ flavor. Because of this, whether the raw material came from China or was domestically produced, these soybean sprouts are often better than those produced in other areas. The Chinese soybean sprouts have a high linolenic acid concentration, which gave them a grassy and bean-like flavour despite their good overall acceptability. Because the Jeonju product contained two to three times less amino acids, such as leucine, tyrosine, and phenylalanine, than the other regional products, which tasted bitter, the soybean sprouts grown using Chinese soybeans in Jeonju were better in the overall acceptability than those grown in other regions. The cultivating water may have an impact on the flavour and free amino-acid content of soybean sprouts. Kim et al. (2016) conducted an analysis of the nutritional contents of soybean sprouts grown with bamboo ash. As soybean sprouting water, bamboo ash was used and adjusted to 0.2-10.0 g/L. Soybean sprouts grown at 0.2 g/L had longer stems, greater isoflavone concentrations (daidzin, glycitin, genestin, daidzein, glycitein, and genestein), higher vitamin C levels, and higher levels of the amino acids asparagine, lysine, leucine, and ornithine compared to sprouts grown with just water and 6-benzylaminopurine addition. The findings showed that soybean sprouts grown with 0.2 g/L bamboo ash were successful in improving nutritional contents. One of the several insects that affect important crops, *Riptortus clavatus*, damages pods and seeds, lowering the vigour and viability of soybean seeds. In a study by Oh et al. (2010), the impact of various *R. clavatus* damage on seeds was investigated in terms of germination, seedling emergence, vigour and quality, and yield of soybean sprouts. When compared to normal seeds, the yield of soybean sprouts from seeds damaged at various degrees dropped by up to 13%. 84% of customers who took part in the survey on customer preferences for soybean sprout produce chose to buy sprouts made from seeds with 5% damaged seeds, whereas just 22% of customers meant to buy sprouts made from seeds with 15% damaged seeds.

5. Factors effecting the yield and quality of soybean sprouts

5.1. Seed size and quality

One of the important considerations when selecting a soybean cultivar for sprout production is seed size. Small to medium-sized seeds typically have better and more consistent germination, making them the ideal choice for sprouting. Additionally, it is known that soybeans with small seeds develop sprouts with a high yield and a nice flavour (Lee et al., 2007). Typically, soybeans with a seed weight of less than 120 mg/seed are favoured for sprout formation. Smaller soybean seeds are reported to absorb water better, develop longer hypocotyls, and have higher germination rates. In addition to seed size, other elements that affect sprout quality and length include seed coat colour, purity, and the removal of broken, damaged, or infected seeds (Ghani et al., 2016).

5.2. Light

Plant physiology is greatly influenced by the surrounding light conditions. Most plants activate their defence mechanisms in response to ultraviolet (UV) radiation, producing UV-absorbing substances such flavonoids that have a variety of biological and pharmacological properties, including antioxidant, anti-inflammatory, and antiallergic properties. The amount of isoflavones in legume crops including soybean, red clover, and astragalus increased when they were exposed to UV radiation at the right intensity and duration. Isoflavones in soybean generally comprise three aglycones (daidzein, genistein, and glycitein) and their respective glycosides. It is well known that genistein and its glycosides are found in high concentrations in the leaves, whereas daidzein and its glycosides are more abundant in the roots than the leaves. Several studies have reported the isoflavone changes in leaves or whole soybean seedlings caused by UV radiation. It is known that soybean root along with the leaves is the main storage site of isoflavones and that UV light can change contents of isoflavones in those organs (Lim et al., 2021). During germination, light can have a negative impact on the quality of soybean sprouts. The cotyledons turn green because light causes photosynthesis to begin and influences root extension. For soybean sprouts, both long roots and green cotyledons are unfavourable (Shi et al., 2010). In general, shorter-rooted sprouts with white hypocotyls that are 8 to 12 cm long and bright yellow cotyledons are highly valued by consumers (Lee et al., 2007). Thus, it is essential to complete the sprouting process in complete darkness to reduce the number of unwanted sprouts.

5.3. Temperature and humidity

Soybean germination, sprout quality, and yield are significantly impacted by air, water, and humidity conditions. Low temperatures have a negative impact on the length, thickness, and quality of the hypocotyl as well as its duration from seed germination to sprout harvest. Generally speaking, during seed imbibition, water temperatures greater than 20°C are desirable (Lee et al., 2007). For high-quality sprout formation, an air temperature of 20 °C to 23 °C is advised during the incubation phase (sprouting time). After starting the germination process, watering the sprouts is crucial to lowering the temperature, eliminating organic matter, and supplying oxygen inside the sprout growth equipment. So, while sprouting, water should be administered multiple times. Additionally, hypocotyl length and width may be positively impacted when the water used for sprinkling is warmer than 21 °C. According to Koo et al. (2015), sprout entire lengths and hypocotyl lengths were twice as long and produced more sprouts when grown at 25 °C as opposed to 20 °C. The sprouts cultured at both temperatures had identical hypocotyl thickness. In order to generate an environment that promotes consistent germination and low seedling disease, relative humidity of 80% is typically advised (Lee et al., 2007).

5.4. Hypocotyls in soybean sprouts

Along with cotyledons, the hypocotyl is a crucial component of sprouts. At sprout harvest, which occurs after 5 days of sprouting, the ideal hypocotyl length and thickness are typically in the range of 8 to 12 cm and 2.0 to 2.2 mm, respectively (Lee et al., 2007). For sprout traits such hypocotyl length and thickness, many soybean varieties developed for this purpose have been shown to show considerable phenotypic diversity (Kim et al., 2013; Kim et al., 2014). Most of these cultivars have hypocotyl lengths > 8.8 cm and thickness >1.8 cm.

5.5. Sprout harvesting time

Harvesting time of the sprouts may vary depending on the factors such as germination rate and water temperature during imbibition and incubation. Additionally, the germination and growth of seeds from old lots are often poor, and it may take them longer to achieve the ideal hypocotyl lengths. However, under most conditions, sprouts can be ready for harvest after 5–7 days after the start of germination. Delaying harvest may reduce the quality of the sprouts, frequently as a result of the unintended growth of lateral roots and leaves (Silva et al., 2013).

5.6. Chemical treatments

A number of issues with soybean sprouts, including poor growth, poor quality, excessive lateral root growth, and seedling rot, can reduce their overall yield and market value. Chemical substances like hormones were examined for their impact on sprout quality and yield in order to manage these aspects. IAA and BA produced sprouts with short root length, a desirable trait favoured in sprout production, after treating soybean sprouts with growth regulators. Utilising organic compounds that control plant growth can help to increase the productivity of the soybean sprout production (Ghani et al., 2016).

6. Genetic variation in the soybean germplasm & breeding soybean varieties for sprout usage

A variety of characteristics, including adaptability, variation in seed coat and hilum colour, leaf form, flower colour, maturity, and seed composition, have been used to classify soybean seeds. Before the advent of modern breeding, a number of regional varieties with tiny seeds and yellow seed coats were used to produce sprouts. Breeders used a number of criteria when selecting soybeans for sprouting, including a 100-seed weight of approximately 10 g, good germination (more than 90% germination after harvesting), seed vigour, bright hypocotyl colour, yellow cotyledons, increased hypocotyl length, and sprout yield (sprout yield %=weight of sprout×100/initial seed weight). Due to rising demand and consumption of sprouts as a vegetable in the late 1990s, soybean breeders increased their breeding efforts to improve soybeans for use as sprouts. High nutritional content and resistance to lodging, shattering, and infections have also been regarded as essential features in sprout breeding programmes. The majority of commercial soybean types have seed coats that are yellow, which is much preferable for growing and eating sprouts. It may be difficult to evaluate and choose sprout-related features phenotypically, especially during the germination stage, as these are greatly influenced by the other parameters (Ghani et al., 2016). In Korea, soybean breeding programmes have placed a focus on breeding new soybean sprout varieties with small seeds, large yields, and resistance to the soybean mosaic virus and black root rot. As a result, a number of new soybean sprout varieties have been commercially introduced (Lee et al., 2015). In Asia, soybean sprouts are a common vegetable, and they are becoming more well-known in the United States. Natto (a Japanese soyfood) cultivars, which share some seed properties with sprout cultivars, have been used to meet the need for soybean sprouts. Natto seeds, however, do not adhere to all sprouting specifications and are therefore rejected by sprout producers. Fungi on seeds can lead to decreased seed quality, and long-term seed storage has an impact on seed germination and seedling vigour. In order to explore the impact of storage on the quality of soybean sprouts, Escamilla et al. (2017) assessed significant seed and sprout features as prospective selection criteria in breeding sprout soybeans. It was advised to breed superb sprout soybean cultivars while concurrently using an acceptable yield and various features: Good sprout varieties should produce high-quality sprouts >48%, average-quality sprouts <38%, low-quality sprouts <14%, sprout yield >5.7 g/g seed, hypocotyl thickness >1.6 cm and hypocotyl length >13 cm. One-year seed storage at room temperature reduced sprout quality. Seed storage over time affects seed germination and seedling vigor, and fungi on seed can cause reduced seed quality.

7. Conclusions

Because it decreases the amount of unwanted chemicals including phytic acid, oligosaccharides, trypsin inhibitors, and molecules with lipoxygenase activity, the seed germination process can be used to enhance the sensory quality and nutritional value of soybean seeds. Vitamins like ascorbic acid, riboflavin, and thiamine as well as phytosterols, tocopherols, isoflavones, and isoflavone aglycones can all significantly increase during germination. Optimum consumption of sprouts can provide the recommended dietary allowance of protein, vitamins, amino acids and isoflavones. The market for soybean sprouts is consistently in demand because of these advantages. Therefore, it is crucial to develop soybean cultivars that can yield premium sprouts. The molecular markers/QTLs strongly associated to seed size can be used in the selection process since soybeans with small seeds are greatly preferred in sprouting. In the majority of small companies today, advantageous features like large hypocotyls with short roots and high soybean sprout product are produced through various chemical applications.

Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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