SOIL ECOLOGY LETTERS

SEL ESSAY
Volume 5 / Issue 4 / 230190 / 2023
https://doi.org/10.1007/s42832-023-0190-6

Soy, soil and beyond

Wee Kee Tan[1], Jingling Zhu[1,2], Jun Li[2], Choon Nam Ong[3,*]

1 NUS Environmental Research Institute, National University of Singapore, 5A Engineering Drive 1, T-Lab, #02-01, Singapore 117411, Singapore
2 Department of Biomedical Engineering, National University of Singapore, 7 Engineering Drive 1, Singapore 117574, Singapore
3 Saw Swee Hock School of Public Health, National University of Singapore, 12 Science Drive 2, Singapore 117549, Singapore
* Corresponding author. E-mail: ephocn@nus.edu.sg (C.N. Ong)
Accepted June 28, 2023

Summary Soy and its quest for future food production.

Soy, or soybean (*Glycine max*), is a leguminous plant that has played a significant role in various civilizations throughout human history. Soybeans are native to East Asia and have been cultivated in China for thousands of years. As a food source, soy has a wide range of uses, they include tofu, tempeh, soy milk, soy sauce, miso, soy-based meat alternatives, desserts and snacks. These products serve as alternatives to animal-based proteins and dairy products for vegetarians, vegans, and individuals with dietary restrictions. In addition, soybean oil is one of the most widely consumed cooking oils globally. It is used for frying, baking, sautéing, and salad dressings due to its mild flavour and high smoke point. Soybean oil is also used as an ingredient in margarine, mayonnaise, and other food products. Soybean meal, a by-product of soybean oil extraction, is a primary source of protein in animal feed. It is used to feed livestock, poultry, and aquaculture species, providing a cost-effective and nutritious protein source. In recent years, soy-based compounds, such as isoflavones, have been studied for their potential health benefits (Pabich and Materska, 2019). Isoflavones are phytoestrogens that are believed to have estrogen-like effects and may have positive effects on heart health, bone health, and menopausal symptoms.

Soy has been a staple in Chinese cuisine and culture for centuries and is an important source of protein, particularly for those who follow a vegetarian or vegan diet. Today, soy-based products like tofu, soy milk, and soy sauce have become widely consumed in many parts of the world. Tofu, for example, with its culinary versatility, has been highly appreciated, especially in Asian food cultures, and could be a potential elixir for Earth's sustainability (Zhu et al., 2023). In fact, soybeans and soy-based products have gone beyond China and have become integral to the cuisines of other East and South East Asian countries, such as Japan, Korea, Vietnam and Indonesia. These nations developed their unique ways of incorporating soy into their traditional dishes.

Soy protein contains well-balanced essential amino acids and is a high-quality protein with protein digestibility-corrected amino acid score (PDCAAS = 1.00) close to some of the proteins from animal sources (Qin et al., 2022). Besides being an excellent source of protein, soybeans are also rich in dietary fiber, vitamins, and minerals, making them a valuable food choice. They are also low in saturated fat and cholesterol, and contain unsaturated fats, including polyunsaturated fatty acids, such as alpha-linolenic acid (omega-3 fatty acid) and linoleic acid (omega-6 fatty acid), making them an excellent alternative to animal-based food source.

The cultivation of soybeans has had a significant impact on agriculture. Soybeans are known for their ability to fix nitrogen in the soil, which benefits subsequent crops. This nitrogen-fixing property has made soybeans a valuable rotational crop, improving soil fertility and reducing the need for synthetic fertilizers.

Soybeans have become a major commodity worldwide. Large-scale cultivation of soybeans takes place in countries like the US, Canada, Brazil, and Argentina. The global demand for is driven by both the growing population and the need for protein-rich food, and not only has had significant economic implications for these countries, but also influenced their agricultural policies.

In brief, soy has had a profound impact on various civilizations throughout history. It has provided nutrition, influenced cuisines, supported agricultural practices, and contributed to industrial development. Its versatility and nutritional benefits have made it an important part of many cultures and societies.

Soy as the foundation for meat analogues and substitutes

The quest for sustainable and nutritious plant-based food

Cite this: Soil Ecol. Lett., 2023, 5(4): 230190

options has led to the emergence of alternative meat proteins, or meat analogs and substitutes, with soy notably being a versatile and widely-selected choice. Such increasing demand has fuelled the development of a diverse array of soy-based products, including soy-based burgers, sausages, and deli meats, which have gained considerable popularity in the market of plant-based protein alternatives (Messina et al., 2022).

Soy serves as a fundamental building block in the creation of meat analogs and substitutes, aiming to replicate the taste, texture, and appearance of traditional meat, while providing a sustainable protein source. The versatility of soy protein enables manufacturers to develop meat substitutes that closely resemble animal-based products, providing a satisfying eating experience.

One of the key advantages of utilizing soy as an alternative meat protein is its environmental sustainability. Traditional animal husbandry demands significant land use, and consumes substantial volumes of water and feed resources, while contributing to deforestation and greenhouse gas emissions (Goldstein et al., 2017). Soy cultivation, on the other hand, requires less land and water, emits fewer greenhouse gases, and is more sustainable when managed responsibly. Opting for soy-based meat substitutes allows consumers to reduce their carbon footprint and contribute to a more environmentally conscious food system.

Soy has thus emerged as a game-changer in the realm of alternative meat proteins, owing to its versatility and nutritional value. Its extensive use in meat analogs and substitutes demonstrates its potential to revolutionize the food industry. By incorporating soy into our diets, consumers can enjoy sustainable, yet nutritious, and delicious plant-based protein options. The culinary possibilities, nutritional benefits, and environmental sustainability offered by soy make it a pivotal component in shaping a more sustainable and compassionate food system.

Toward zero waste: Harnessing the power of soy for agriculture

The high consumption of soy products, however, resulted in a massive volume of soy waste (okara) being generated during the production process. This by-product is the pulpy residue left behind during tofu-making or after extracting soy milk from soybeans. Okara is sometimes used as animal feed, particularly for livestock and poultry. Its high protein content and fiber make it a valuable component in animal diets. Okara can also be composted or used as a natural fertilizer due to its nutrient-rich composition. When added to compost piles or used as a soil amendment, it enhances the organic matter content, improves soil structure, which promotes microbial activity and nutrient availability to plants, thus promoting healthier plant growth.

Recently, an innovative approach to transform okara waste into a superabsorbent hydrogel was reported (Zhu et al., 2020). The hydrogel can be used as a soil supplement to combat climate change and boost plant growth for a greener future in agriculture. This okara-derived hydrogel can expand few hundred times its dry weight when in contact with water, making it a mini reservoir that holds water in the soil for longer periods of time for plant roots to tap on. By minimizing excessive leaching, it increases the water-use efficiency and simultaneously locks in the nutrients as reserves in the soil, thus reducing the usage of fertiliser (Tan et al., 2021).

To demonstrate the use of okara-derived hydrogel in agriculture, we use kailan (*Brassica oleracea*), a common Asian vegetable, in our experiments. Under drought conditions, plants wilt, as reflected by the shrivelling of the plant leaves (Fig. 1, photo insets), resulting in substantial decrease in the leaf area (Fig. 1, arrow) through phenotyping imaging. In the presence of the superabsorbent hydrogel, the degree of the

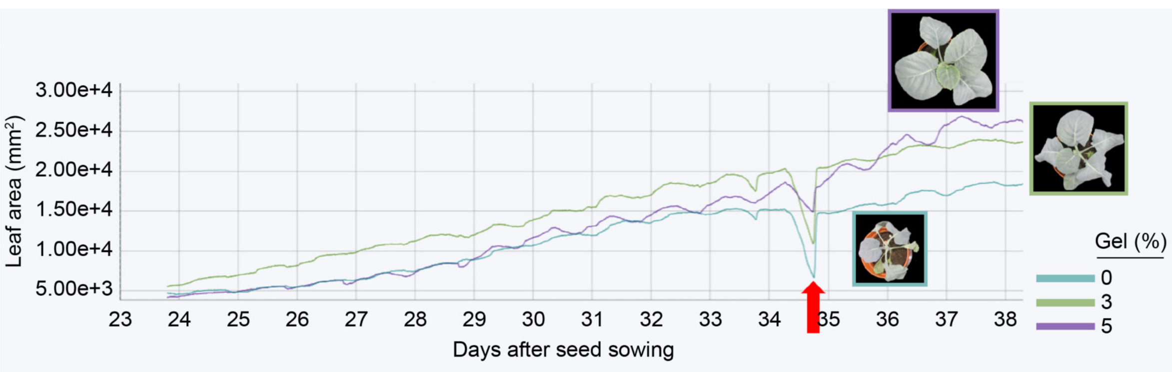

Fig. 1 Non-destructive phenotypic monitoring of the leaf area of kailan (*Brassica oleracea*) over time. Plants wilting as reflected by a dip in the graph due to the shrivelling of the leaves (photo insets) 34 days after seed sowing (red arrow) prior to the next irrigation, with more drastic effect observed in the absence of okara-derived hydrogel (turquoise outline) compared to plants that were grown with 3% (green outline) or 5% (purple outline) of the hydrogel.

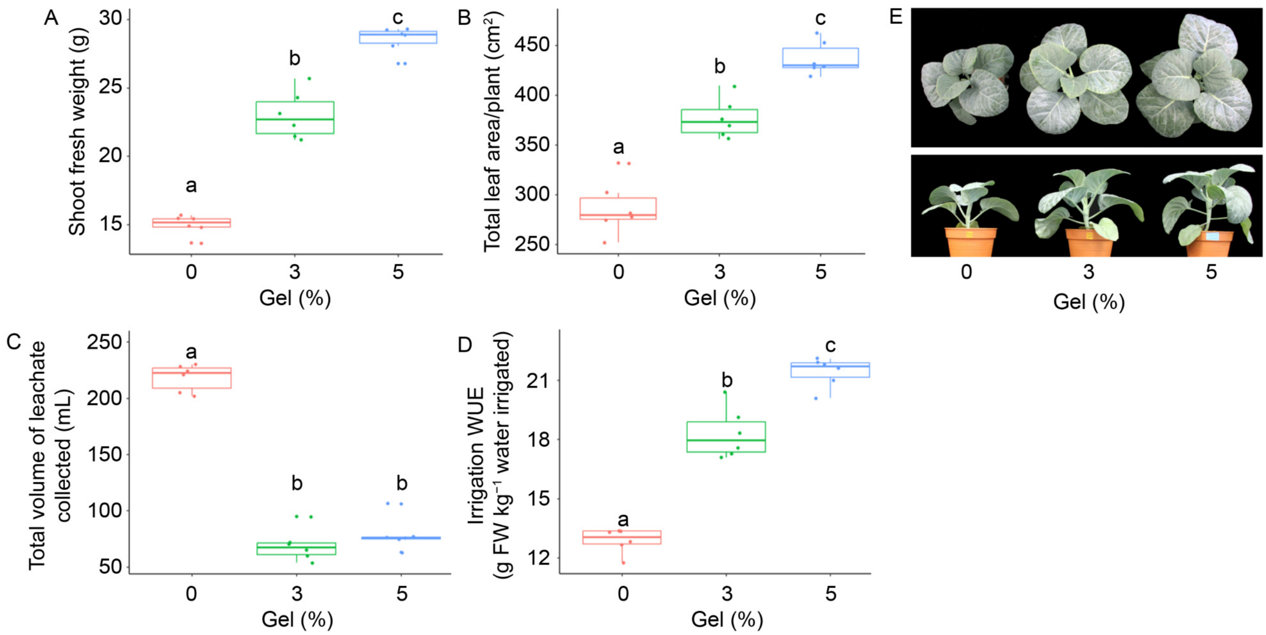

Fig. 2 Effect of okara-derived hydrogel on the growth and water-use efficiency of kailan under water-limited conditions. Incorporation of okara-derived hydrogel enhances the yield [i.e., shoot fresh weight (A), total leaf area (B)], minimizes leaching (C) and improves the irrigation water-use efficiency (WUE; D). (E) Top (top panel) and side (bottom panel) views of representative plants in response to addition of hydrogel.

wilting is much reduced, especially when higher concentration of the hydrogel was incorporated (Fig. 1, photo insets). Significantly higher yield in terms of shoot fresh weight (50%–90% increase; Fig. 2A) and total leaf area per plant (30%–50% increase; Fig. 2B) could be observed. The degree of leaching was also reduced by more than 60% (Fig. 2C) and a concomitant increase in the irrigation water-use efficiency (40%–65% increase; Fig. 2D) was noted. These findings suggested an overall enhancement of the growth of the vegetables (Fig. 2E). Hence, with the incorporation of the hydrogel, plants can tap into the water and nutrient reserves in the soil, thus increasing their survivability and growth.

In field experiments, this okara-derived hydrogel has also been shown to increase the water-use efficiency and enhance the growth of vegetables (Zhu et al., 2022). With climate change resulting in more frequent droughts, innovative solutions, such as the use of okara waste-derived hydrogel, can help us meet the growing need for food production. Leveraging on such revolutionary technologies not only address the agricultural production challenges ahead, but further contribute to waste valorisation and a more sustainable circular economy.

Acknowledgments

This work was supported by the National Research Foundation, Prime Minister's Office, Singapore (Grant No. NRF-2020-THE003-0005).

References

Goldstein, B., Moses, R., Sammons, N., Birkved, M., 2017. Potential to curb the environmental burdens of American beef consumption using a novel plant-based beef substitute. PLoS One 12, e0189029.

Messina, M., Sievenpiper, J.L., Williamson, P., Kiel, J., Erdman, J.W. Jr, 2022. Perspective: Soy-based meat and dairy alternatives, despite classification as ultra-processed foods, deliver high-quality nutrition on par with unprocessed or minimally processed animal-based counterparts. Advances in Nutrition 13, 726–738.

Pabich, M., Materska, M., 2019. Biological effect of soy isoflavones in the prevention of civilization diseases. Nutrients 11, 11.

Qin, P., Wang, T., Luo, Y., 2022. A review on plant-based proteins from soybean: Health benefits and soy product development. Journal of Agriculture and Food Research 7, 100265.

Tan, W.K., Zhu, J., Lim, J.Y., Gao, Z., Loh, C.S., Li, J., Ong, C.N., 2021. Use of okara-derived hydrogel for enhancing growth of plants by minimizing leaching and locking nutrients and water in growing substrate. Ecological Engineering 159, 106122.

Zhu, J., Suhaimi, F., Lim, J.Y., Gao, Z., Swarup, S., Loh, C.S., Li, J., Ong, C.N., Tan, W.K., 2022. A field study on using soybean waste-derived superabsorbent hydrogel to enhance growth of vegetables. Science of the Total Environment 851, 158141.

Zhu, J., Tan, W.K., Song, X., Gao, Z., Wen, Y., Ong, C.N., Loh, C.S., Swarup, S., Li, J., 2020. Converting okara to superabsorbent hydrogel as soil supplement for enhancing growth of choy sum (*Brassica* sp.) under water-limited conditions. ACS Sustainable Chemistry & Engineering 8, 9425–9433.

Zhu, Y.G., Yang, Y., Mouritsen, O.G., 2023. Tofu—a diet for human and planetary health. Soil Ecology Letters 5, 220163.