Trends in Food Science & Technology 59 (2017) 1–14

Contents lists available at ScienceDirect

Trends in Food Science & Technology

journal homepage: http://www.journals.elsevier.com/trends-in-food-science-and-technology

Review

Bioactive compounds and bioactivities of germinated edible seeds and sprouts: An updated review

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ARTICLE INFO

Article history:
Received 14 March 2016
Received in revised form
26 August 2016
Accepted 9 November 2016
Available online 23 November 2016

Keywords:
Germination
Edible seeds
Vitamins
γ-Aminobutyric acid
Polyphenol
Antioxidant capacity

ABSTRACT

Background: **Germination** has been widely employed to produce germinated **edible seeds** and sprouts for consumption in our daily life. Through simple germination procedures, many edible seeds can be germinated in a short time with improved nutritional and medicinal values. Understanding the main bioactive compounds and bioactivities of germinated edible seeds and sprouts can be helpful for their better utilization as functional foods.
Scope and approach: This review mainly summarizes recent studies about the bioactive compounds and bioactivities of germinated edible seeds and sprouts, and the potential molecular mechanisms of accumulating bioactive compounds in germination are discussed.
Key findings and conclusions: Germination can accumulate different bioactive compounds, such as **vitamins**, **γ-aminobutyric acid** and **polyphenols**, and this can be dependent on *de novo* synthesis and transformation. In addition, germinated edible seeds and sprouts possess many bioactivities, such as their **antioxidant capacity**, which is significantly increased after germination. Therefore, germination can be a green food engineering method to accumulate natural bioactive compounds, and those germinated edible seeds and sprouts rich in natural bioactive compounds can be consumed as functional foods to prevent chronic diseases.

1. Introduction

Edible seeds, such as pulses and cereal grains, are important dietary components for human. In addition, this year 2016 is "The International Year of Pulses", indicating the importance of edible seeds, especially pulses, in the current global nutrition. As indicated by FAO, of more than 50,000 edible plant species in the world, only a few hundred are important and nutritious food sources. Among them, pulses play an important role globally in human nutrition, being high in protein, vitamins, minerals and dietary fibre. Pulses generally have amino acid composition complementary to the major cereals, therefore, combined consumption of pulses and cereals increases the overall protein quality of the meal, which is most important for people in some developing countries. In addition, edible seeds contain different phytochemicals, and possess many biological functions, such as antioxidant, antidiabetic and antitumor effects (Hayat, Ahmad, Masud, Ahmed, & Bashir, 2014; Verspreet, Dornez, Van den Ende, Delcour, & Courtin, 2015). Recent studies show that germination can further enhance the nutritional and medicinal values of edible seeds. On one hand, it leads to the catabolism and degradation of main macronutrients, such as carbohydrates, protein and fatty acids, accompanied with the increase of simple sugars, free amino acids and organic acids (Shi, Nam, & Ma, 2010; Wang et al., 2005). On the other hand, it can reduce anti-nutritional and indigestible factors, such as protease inhibitors and lectin (Aguilera et al., 2013). Additionally, it can accumulate some secondary metabolites in edible seeds, such as vitamin C and polyphenols (Gan, Wang, Lui, Wu, & Corke, 2016). Furthermore, germinated edible seeds have been reported with many bioactivities, such as antioxidant, antidiabetic and anticancer effects. Therefore, germination is a good way to improve the health benefits of edible seeds, and edible bean sprouts, such as mung

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http://dx.doi.org/10.1016/j.tifs.2016.11.010
0924-2244/

bean and soybean sprouts, are popular in some developing countries, such as some eastern Asian countries.

Based on Web of Science and Pubmed, we searched for English language articles on germination of edible seeds from 2000 to date. Germination of cereals has been reviewed in three recent papers (Hubner & Arendt, 2013; Omary, Fong, Rothschild, & Finney, 2012; Singh, Rehal, Kaur, & Jyot, 2015), where they are mainly focused on the influences of germination on macronutrients in cereals, but there is a lack of an updated review to highlight the importance of germination on bioactive compounds and bioactivities of edible seeds, mainly pulses and grains. Therefore, in this review, we first briefly described the germination strategies, and then summarized the bioactive compounds and their contents as well as the related analytic methods in germinated edible seeds and sprouts, followed by discussion of the potential mechanisms in the accumulation of bioactive compounds during germination, and finally highlighted the bioactivities of germinated edible seeds and sprouts, mainly focusing on antioxidant capacity.

1.1. Germination strategies

The germination strategies can be carried out in several simple procedures, mainly sterilization, soaking and sprouting. For different seeds, the germination strategies may vary, however, the basic principles and procedures are generally consistent, as described below.

1.2. Sterilization

In order to inhibit the growth of microbes, sterilization is performed before the soaking of seeds. According to the literature, sodium hypochlorite (NaClO) solutions with different concentrations are the most commonly used sterilization reagents for seed germination, especially 0.07% NaClO solution (Limon, Penas, Martinez-Villaluenga, & Frias, 2014). When using NaClO solutions, the sterilization is generally performed at room temperature for 5–30 min, with the seed weight (g)/solution volume (mL) ratio 1: 5 or 1: 6. In addition, ethanol or 70% ethanol is also reported to sterilize seeds, with the sterilization time no more than 3 min (Pajak, Socha, Galkowska, Roznowski, & Fortuna, 2014; Wu et al., 2012). However, few studies investigated the influences of sterilization on the germination results. On the other hand, some studies did not perform the sterilization step before soaking of seeds (e.g. Guajardo-Flores, Serna-Saldivar, & Gutierrez-Uribe, 2013; Guo, Li, Tang, & Liu, 2012), probably considering the potential hazardous effects of sterilization reagents on the seeds and food safety risks for consumption. Therefore, sterilization is not obligatory for seed germination, and whether sterilization is needed should be dependent on the condition of seeds, the frequency of changing water during the sprouting process and the purpose of germination.

1.3. Soaking

Before sprouting, seeds should be soaked in water to rehydrate, and the soaking temperature, time and the ratio of seed weight (g)/water volume (mL) should be considered for seed soaking. Generally, seeds can be soaked at room temperature (about 20–30 °C), with the soaking time from several hours to 24 h and the ratio of seed weight (g)/water volume (mL) from 1: 1.5 to 1: 20. These differences of seed soaking condition should be associated with the intrinsic characteristics of different seeds, such as the capacity of absorbing water, the thickness of seed coats and the size of seeds.

1.4. Sprouting

After soaking, seeds can be put in special germinators or incubators for sprouting. There are several factors should be considered for seed sprouting, such as the light, temperature, humidity, watering and time. Sprouting of seeds is commonly performed in the dark and the sprouting temperature is generally kept at 20–30 °C. During sprouting, seeds should be watered everyday to keep relatively high humidity in order to support their growth, and water should be frequently changed, such as twice a day, in order to remove the metabolites of germinated seeds and to inhibit the growth of microbes. For the sprouting time, it is dependent on the purpose of germination. For common edible beans, 3–5 day is usually enough for bean sprouts to reach an edible length.

Overall, the germination is a very simple, inexpensive, environmental-friendly and safe way to cultivate the germinated seeds and sprouts within a short time. However, there are currently only several cultivated edible sprouts consumed in human diets, such as mung bean, soybean and peanut sprouts. In light of the cultivation advantages and accumulation of bioactive compounds and bioactivities during germination as discussed below, it is highlighted that germination can be an important bio-processing trend in the field of food science and technology to produce functional germinated seeds and sprouts.

2. Bioactive compounds

Recent studies indicate that germination can accumulate various bioactive compounds in germinated seeds and sprouts, such as vitamins, γ-aminobutyric acid (GABA) and polyphenols. These bioactive compounds can be *de novo* synthesized or transformed in the germination process. Here, we summarize the main bioactive compounds and their contents as well as their analytic methods in germinated edible seeds and sprouts, and pay special attention to the influence and potential mechanisms of germination on changes in these bioactive compounds.

2.1. Vitamins

Vitamins are a group of organic compounds widely distributed in the plant kingdom and play important functions in human health. Generally, they can be divided into water-soluble and fat-soluble vitamins. The former mainly includes vitamin B and C, and the latter contains vitamin A, D, E and K. Recent studies find that germination can significantly increase the content of some vitamins.

B vitamins include several members, including vitamin B1 (thiamine), vitamin B2 (riboflavin), vitamin B3 (niacin), vitamin B6 (pyridoxine), vitamin B9 (folate) and vitamin B12 (cobalamin), all of which play important roles in human health and diseases (Moran & Greene, 1979; Selhub, Troen, & Rosenberg, 2010). Germination has been found to increase the content of some B vitamins in different seeds (Table 1). Compared to raw seeds, folate was significantly increased in soybean and mung bean sprouts, by 65%–274% and 78%–326%, respectively (Shohag, Wei, & Yang, 2012), and vitamin B1 and B6 were about 11.8 mg/100 g DW in buckwheat sprouts, while they could not be detected in raw seeds (Kim, Kim, & Park, 2004). However, to our knowledge, the biosynthesis pathway of vitamin B has not been reported.

Vitamin C, also known as ascorbic acid, is associated with the diseases scurvy. Fruits and vegetables are the main natural sources of vitamin C, however, recent studies find that germination can significantly increase the content of vitamin C in some germinated edible seeds and sprouts, (Table 1), such as germinated buckwheat, chickpea, cowpea, lupin, mung bean and soybean or their sprouts.