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Effect of cooking on physicochemical properties and volatile compounds in lotus root (*Nelumbo nucifera* Gaertn)

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ABSTRACT

The effects of boiling and steaming on lotus root volatile compounds and some of its physicochemical properties were determined. A total of 52 compounds identified in the raw tuber by GC–MS were a combination of the rhizome's native compounds and those from the soil and water environment, and are predominantly a mixture of straight chain and cyclic alkanes, and aromatic hydrocarbons. Boiling increased concentrations of most of these compounds, unlike steaming that lowered total volatile components of the tuber. Cooking increased complexity of volatile compounds with the production of new compounds such as methylated derivatives, particularly in steam cooked lotus. Other heat-induced compounds include antioxidants such as butylated hydroxyl compounds and antifungal organic compounds such as dimethyl disulfide. Instrumental texture measurements indicate that the characteristic post-cooked retention of crunchiness in lotus root is likely to be related to retention of its springiness index through the cooking process.

1. Introduction

Lotus (*Nelumbo nucifera* Gaertn), a perennial aquatic crop, is one of two species of aquatic plant in the family *Nelumbonaceae* and widely cultivated throughout Orient. It is an important plant of economic value which produces roots that are very popular as a vegetable because of its crispness, attractive white color and abundant nutrients. They can be consumed either raw or cooked and are believed to be rich in health promoting compounds (Ji et al., 2015), such as flavonols, alkaloids, nuciferine and aporphine, lipids, phospholipids, flavonoids, carotenes, xanthophylls, and many minerals. Lotus root is cultivated throughout China, particularly in the provinces that have a large number of catchments and rivers such as Zhejiang, Jiangsu, Jiangxi, Hunan, Hubei, Anhui, Guangdong, and Fujian province. Lotus rhizome, known as Lianngau or Ou in Chinese, is a staple food in many Asian countries, often used as ingredients in the preparation of important traditional food items, such as vegetable in soups, deep-fried, stir-fried, and braised dishes. While there has been considerable interest in identifying the bioactive compounds and factors that contribute to its processing qualities, there appears to be no report on the flavor characteristic and effect of cooking on their constituent volatile compounds.

The tuberous nature of the lotus root suggests that it will have a number characteristic traits and composition similar to other types of modified plant structures that are enlarged to store nutrients such as potato, sweet potato and cassava. However, differences from these traditional tubers can be expected in that unlike most tubers, they are planted in soils of ponds or river bottom. Their cultivation and growth in soils with large quantities of water will also potentially confer properties similar to other aquatic plants and vegetables. Cooking methods significantly impact flavor compounds in tubers (Oruna-Concha, Jokie Bakker, & Ames, 2002) and studies have been conducted to determine sensory impact such as aroma, color and texture of different cultivars on boiled and steam-cooked potatoes, as they relate to texture and dry matter content (García-Segovia, Andrés-Bello, & Martínez-Monzó, 2008). However, the sensory characteristics (texture, aroma and color) of cooked lotus have seldom been the focus of attention for groups of research. There appears to be no published work on volatile and other constituent compounds that could impact the aroma of fresh, steamed or boiled lotus roots.

This study was conducted to determine the composition of volatile composition of fresh lotus root, and how these are affected by the cooking process. Some physicochemical properties of the fresh and cooked rhizome were also determined. Information provided from this investigation provides insight to volatile compounds and physicochemical properties that could impact flavor

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and texture of lotus root and aquatic vegetables, and their potential effects on their fresh and processed products. Additionally, it forms the basis for further research in areas vital to understanding the overall development of flavor compounds in raw and cooked tubers, the extent of impact of an aquatic environment on the development of these compounds, and how they might be leveraged to enhance the quality of their processed products.

2. Experimental

2.1. Materials

Collection of "Elian No.5-35 (E35)" fresh lotus root samples from local growers in Hubei province was coordinated through Hubei Linghu Shangpin Agricultural Development Co. Ltd., China. Samples collected were usually brought to our laboratory in cold storage within 12 h after harvest. The lotus roots used were grown using the standard cultivation practices. Upon arrival, the muddy coatings are rinsed off with cold water and the roots are wiped dry. The cleaned uncut tubers were stored at 4 °C until used, which is typically within 24 h of their arrival at our laboratory. Samples representing a minimum of three replicates were then randomly selected for each analysis and were independently analyzed for the parameters determined.

2.2. Determination of physicochemical and textural properties of fresh lotus root

Moisture content of fresh lotus root was determined using the heterogeneous azeotropic distillation process (ISO 1026-1982). Cut lotus root samples (5.0 g) were blended with methylbenzene (75 mL) and transferred into a distillation flask, which was attached with condensate return equipment. The mixture was distilled and the condensed water was collected. Humidity of samples was calculated from calibrated standards.

Measurement of volatile acidity was carried as described in ISO 6632-1981 with minor modifications. A mixture of lotus root pieces (10.0 g), water (20 mL) containing a mixture of tartaric acid (0.5 g) and tannic acid (0.2 g) was steam distilled. The distillate (250 mL) was collected and the volatile compounds were neutralized with sodium hydroxide, the consumption of which represented the volatile acidity of lotus.pH and soluble solid contents were determined from a blend of lotus root pieces (25 g) with distilled water (15 mL). pH was measured from the pulverized root using a pH meter (FE20, METTLER). The mixture was then filtered through a cheese cloth and soluble solids were determined on the filtrate using a refractometer (PR-32α, ATAGO).

Texture profile analysis (TPA) was performed using the texture analyzer equipped with a TA.XTPlus Texture Analyzer (England Stable Micro System CO, Ltd), in which Texture Expert for Windows (Texture exponent 32 software) was equipped with a cylinder probe (Type p/45). The texturometer was programmed so that the downward movement of the cylindrical flat-end punch (4.5 cm Diameter) began at a point 10 mm above the surface of the sample. The pretest and posttest speed was kept at 10 mm/s, and the test speed was 0.5 mm/s. Five replicates of the lotus root samples (1 cm^3) placed on a flat aluminum base were compressed to 35% of their initial height, held for 5 s and compressed again.

2.3. Determination of volatile compounds in fresh lotus root

Lotus root samples (E35), raw, steamed or boiled for different times, were peeled and sliced to approximately 1 cm thickness. The cut pieces (100 g) were transferred into a blender and NaCl (30 g) was added. The mixture was pulverized for 30 s, after which 1,2-dichlorobenzene (6.76 μg) internal standard was added. This was followed by further pulverization for 1 min. Extraction of volatile compounds from the admixture was carried out using a solvent mixture containing pentane and dichloromethane (v:v, 2:1; 60 mL) which was kept at −20 °C prior to use (Kilic, Hafizoglu, Kollmannsberger, & Nitz, 2004). Solvents used for extraction were over 99% pure and were used without further purification. The resulting organic layer was collected and kept at −80 °C for 40 min to remove water. The extract (8 mL) was filtered through a 0.2 μm syringe filter after drying over anhydrous sodium sulfate, and concentrated by blowing a stream of nitrogen gas over it until the volume was about 1 mL.

The volatile compounds in the lotus root extracts were analyzed by gas chromatography-mass spectrometry (GC–MS), on a 7890A/MSD5975C instrument (Agilent Technologies Co. Ltd., Santa Clara, CA, USA). Samples (2 μL) were injected onto the DB-5 MS column (30 m × 0.5 mm × 0.5 μm) used for the separation of compounds. Two analytical standards, undecane and dodecane (Sigma-Aldrich Co. St. Louis, MO, USA), were used to calibrate column retention times. The temperature program was started at 4 °C and held for 5 min, after which it was raised to 70 °C over a period of 14 min, and then up to 90 °C over a period of 10 min. This temperature was held for 3 min then followed by a gradient increase to 180 °C at the rate of 3 °C/min, held at 180 °C for 3 min before being heated up to 240 °C at the rate of 5 °C/min, and then kept at that temperature for 10 min. The vaporizer temperature was at 250 °C. The helium carrier gas was used to maintain a pressure of 12 psi on the column and the flow rate of 1 mL/min. Ion source temperature for mass spectrometer, operated in a splitless EI mode at 70 eV was 200 °C, and the detection voltage was 350 V. Identification of the resulting peaks was carried out by comparing the compound's Kovats' retention index and mass spectrum, ran using the same stationary phase, found in two mass spectral databases of the National Institute of Standards and Technology (NIST, 2011) and the WILEY.L/NBS75k.L search library. The retention indices were also compared with values found in the literature (Adams, 2007). Compounds were considered to be positively identified when both their mass spectra and retention index were consistent with those in the databases and values reported in literature. Concentrations of the compounds were estimated based on their respective peak areas relative to that of the internal standard.

2.4. Cooking procedures for lotus root

Fresh lotus root (E35 cultivar) was washed, dried and weighed (typical weight 100 ± 0.5 g) prior to processing. Triplicate samples were cooked by two different procedures, i.e. steaming and boiling, and then sensory characterized through Texture Analyzer and Gas chromatography-mass spectrometry as described previously. Internal fresh lotus was immersed in 100 °C of boiling water or exposed to the water vapor for 10 or 60 min, after which the bulk was immediately transferred. For comparison, the raw, steamed and boiled lotus roots were analyzed simultaneously.

2.5. Statistical analysis

Completely randomized design was used throughout the study. The experiments were run in three replicates. The data was analyzed by Excel 12.0, which was presented as mean values ± standard deviation (means ± SD). The significance of difference between groups was determined using analysis of variance (ANOVA) of OriginPro 8.0.