Photo-fermentation of purple sweet potato (*Ipomoea batatas* L.) using probiotic bacteria and LED lights to yield functionalized bioactive compounds

Joeng-Ho Lee¹ · Palanivel Velmurugan^{2,3} · Jung-Hee Park² · Woo-Suk Chang⁴ · Yool-Jin Park⁵ · Byung-Taek Oh^{2,6}

Received: 27 April 2018 / Accepted: 22 June 2018 / Published online: 28 June 2018
© Springer-Verlag GmbH Germany, part of Springer Nature 2018

Abstract

The purpose of this study was to examine if fermentation of purple sweet potato (*Ipomoea batatas* L.) powder (PSP) by *Lactobacillus brevis* under green, red, blue, white light-emitting diode (LED) illumination or sunlight might yield functionalized products with good antibacterial, antioxidant activity, and/or cytotoxic activity. The Purple sweet potato (PSP) powder fermented with probiotic bacteria *L. brevis* under white LED light ($1.9 \pm 1.80/1.6 \pm 0.52$), blue LED light ($1.4 \pm 1.32/1.8 \pm 0.83$), or sunlight ($1.2 \pm 1.26/1.5 \pm 1.83$) for *Propionibacterium acne* and *Staphylococcus epidermidis* displayed good to moderate antibacterial activity based on minimum inhibitory concentration (MIC) red, blue, white LED lights and sunlight (80 µg/mL) for *P. acne* and *S. epidermidis*, minimum bactericidal concentration red, blue LED lights and sunlight shows (46/48, 61/70, 50/48 µg/mL) for *P. acne* and *S. epidermidis*. Antioxidant activity for dark, white, blue and green LED lights for ABTS and white, blue and green Led for DPPH assay resulted in lower activity. Fourier transform infrared spectroscopy was performed to determine the functional groups in the non-fermented (control) and fermented products of PSP powders obtained using different light sources. Sunlight, white, and blue LED light-fermented extracts contained alcohol, acid, and phenol groups, as well as aliphatic amines. The results of this study clearly indicate that fermentation of purple sweet potato with probiotic bacteria under various LED light sources can yield compounds that can be used in cosmetic and value-added food products.

Keywords Purple sweet potato · Probiotics · LED lights · Fermentation · Biomedical

Introduction

Plant-based bioactive compounds are used in several biomedical applications, but there is currently great interest in exploring the potential biomedical applications of fermented and fabricated bio-derived materials (Ige et al. 2012; Halib et al. 2017). To achieve hybrid and effective bioactive compounds from fermented products, fermentation needs to be initiated. This can be done using various types of microorganisms, especially probiotic bacteria (Oh et al. 2017). However, the production of bioactive compounds by microbial fermentation is limited in the absence of light. Light of different wavelengths can stimulate the activity of microbes and yield new active compounds (Hussain et al. 2012; Conlon and Bird 2014). We designed this study to examine the effects of various color LED lights, sunlight, and darkness on the yield of bioactive compounds during fermentation of purple sweet potato by the probiotic bacterium *Lactobacillus brevis*.

✉ Byung-Taek Oh
btoh@jbnu.ac.kr

¹ Sunchang Reserch Institute of Health and Longevity, Sunchang, Jeonbuk 56015, South Korea

² Division of Biotechnology, Advanced Institute of Environment and Bioscience, College of Environmental and Bioresource Sciences, Chonbuk National University, Iksan, Jeonbuk 54596, South Korea

³ Department of Microbiology, Sri Sankara Arts and Science College, Enathur, Kanchipuram, Tamil Nadu 631561, India

⁴ Department of Biology, University of Texas-Arlington, Arlington, TX 76019, USA

⁵ Department of Ecology Landscape Architecture-Design, College of Environmental and Bioresource Sciences, Chonbuk National University, Iksan, Jeonbuk 54596, South Korea

⁶ Plant Medical Research Center, College of Agricultural and Life Sciences, Chonbuk National University, Jenoju, Jeonbuk 54896, South Korea

Sweet potato (*Ipomoea batatas* L.) is an edible root that belongs to the family Convolvulaceae. It originated in Latin America (Esatbeyoglu et al. 2017) and was introduced to Asia during the sixteenth century. Sweet potato is recognized by the Food and Agriculture Organization (FAO) as one of the most global important food crops. There are different varieties of sweet potato that differ in skin color, e.g., white, yellow, orange, pink, purple, and deep purple (Teow et al. 2007; Trung et al. 2017). The deep color of purple sweet potatoes (PSPs) is due to the presence of highly acylated anthocyanins, with cyanidin or peonidin as the aglycone (Zhang et al. 2015; Surendra Babu et al. 2015; Esatbeyoglu et al. 2017). The presence of anthocyanins in PSPs are natural pigments that are beneficial to health (Nagamine et al. 2014; Velmurugan et al. 2017). Several previous reports have shown that PSP constituents have antioxidant, anti-inflammatory, anticarcinogenic, chemopreventive, and antihyperglycemic activities (Konczak-Islam et al. 2003; Hu et al. 2004; Esatbeyoglu et al. 2017).

Lactic acid bacteria (LAB) have traditionally been used to ferment plant-based foods and for preservation. During fermentation, probiotic bacteria produce various bioactive compounds, thereby enhancing nutritional quality and providing health benefits beyond basic nutrition (Limon et al. 2015; Oh et al. 2017). When *Bacillus amyloliquefaciens* and *L. brevis* ferment fruit, they utilize glucose as a hydrophilic carbon source and fatty acids as a hydrophobic carbon source to produce compounds that have anticancer, antimicrobial, dermatological, immunoregulatory, spermicidal, and antiviral activities (Oh et al. 2017).

Previously, Hai et al. (2000) and Yan et al. (2013) reported that LEDs have the potential to be used in bioreactors to cultivate algae and *Spirulina platensis*. LEDs are electroluminescent, and the color of the light generated is determined by the band gap of the semiconductor. LEDs can emit high-intensity light using low energy. The main objective of this study was to investigate the bioactive compounds produced by fermentation of PSP powder with *L. brevis* using different light sources (sunlight, LED lights, and darkness). We used blue ($460 < \lambda < 490$), red ($620 < \lambda < 645$), green ($520 < \lambda < 550$), and white ($380 < \lambda < 780$) LED lights. In addition, the functional groups of the obtained bioactive extracts were determined by FTIR analysis, and their antibacterial, antioxidant, and cytotoxic effects were evaluated.

Materials and methods

Raw material

To prepare raw material for fermentation, commercially available dried purple sweet potato (PSP) fine powder (5 kg) was obtained from an online market based in South Korea.

Probiotic bacteria for PSP fermentation

According to the protocol described in Oh et al. (2017), probiotic bacteria were obtained from the traditional south Korean dish of fermented starfish. The probiotic characteristics of the isolated strains were examined as described in Plessas et al. (2017). We isolated a total of 60 bacterial strains from 1 g of fermented starfish by grinding the sample using a ceramic mortar and pestle along with saline, followed by serial dilution and plating on MRS (de Man, Rogosa, and Sharpe) agar medium and incubation at 37 °C. After incubation, plates were screened to examine colony morphology. Colonies with a unique morphology were isolated, streaked on fresh MRS medium to obtain pure cultures, and then identified based on 16S rRNA gene sequencing (Cosmo Genetech Laboratory, South Korea). Sequences were compared with those in the National Center for Biotechnology Information (NCBI) database using the BlastN search program, and the closest matching species were identified. Pure cultures were stored at −80 °C in MRS supplemented with 20% (v/v) glycerol for subsequent experimentation. To ensure the purity of the culture, each strain was subcultured twice before each experiment. All obtained pure cultures were used for PSP fermentation under different light sources and in the dark. Samples were withdrawn every 12 h for up to 96 h to evaluate changes in bacterial populations, and the potency of the various probiotic cultures was determined based on the maximum number of live colonies obtained at every sampling stage. The most potent strain was used for subsequent experiments.

LED light chamber setup for fermentation

Commercially available LED light illumination strips of different colors and plastic bowls were purchased online. LED strips were pasted inside the wall of the plastic bowl (Fig. 1) and connected to a 12 V power supply. Green, red, blue, and white LED lights were assembled in separate plastic bowls. Erlenmeyer flasks containing probiotic bacteria and PSP powder were placed on a rotary shaker (120 rpm), covered with an LED-containing bowl, and maintained at the appropriate temperature. The entire LED setup was assembled by researchers in our laboratory.

Preparation for liquid state fermentation (LSF)

About 10 g of PSP was suspended in sterile distilled water (1:6 w/v) in a 250 mL-Erlenmeyer flask and autoclaved to eliminate indigenous microbiota present on sweet potato. The most potent probiotic bacterial species identified, namely *L. brevis* (Oh et al. 2017), was inoculated into

Fig. 1 Schematic illustration of purple sweet potato, purple sweet potato powder, LED light setup, fermentation, and biomedical applications

separate flasks (10^8 CFU/mL) and incubated at 37 °C with continuous agitation at 80 rpm using different LED lights, sunlight, and in the dark. Biochemical analysis of samples was performed every 12 h during fermentation. To prepare extract powders, samples were centrifuged at 1610g for 15 min at 6 °C, and supernatants were freeze-dried using a lyophilizer (FD5518, Ilshin Lab Co. Ltd., Korea) followed by storage at -20 °C for further analysis. The antibacterial, antioxidant, and cytotoxic activities of the lyophilized powder samples were assessed.

Fourier transform infrared (FT-IR) analysis

FT-IR spectra of unfermented purple sweet potato powder (control) and fermented PSP powders obtained after incubation under various light conditions by *L. brevis* were recorded using a Perkin-Elmer FTIR spectrophotometer (Perkin-Elmer, Norwalk, CT) in diffuse reflectance mode at a resolution of 4 cm^{-1} in KBr pellets.

Antibacterial activity

Zone of inhibition (ZOI), minimum inhibitory concentration (MIC), and minimum bactericidal concentration (MBC) of unfermented PSP powder (control) and fermented PSP powders were tested against *Propionibacterium acne*

(KACC-11946) and *Staphylococcus epidermidis* (KACC-13234) (KACC, Korean Agricultural Culture Collection), which cause skin infections. Pathogen cultures (*P. acnes* was grown under anaerobic conditions and *S. epidermidis* under aerobic conditions) were enriched in BHI broth (MB Cell, Seoul, South Korea). ZoI was determined by spreading cultures grown in BHI broth on Muller–Hinton agar (MH) (MB Cell, Seoul, South Korea) plates seeded with a 0.5 McFarland scale bacterial suspension. Agar plates were punctured to create 4-mm-diameter depth wells, which were then filled with different concentrations (25, 50, 100, and 200 mg/0.5 mL) of fermented PSP powders or unfermented PSP powder (control), followed by incubation at 37 °C. After incubation, clear zone formation, indicating inhibition of bacterial strains, was investigated. Mean zone diameters were expressed in millimeters. MICs of the extracts were determined by preparing different concentrations (160, 80, 40, 20, and 10 mg/mL) of each fermented extract and control extract. These were then inoculated with ca. 100 μL of 10^8 CFU/mL mid-log cultures of *P. acnes* and *S. epidermidis* in 96-well microtiter plates with appropriate blanks, followed by incubation. After incubation, the turbidity of the growth medium was measured at 600 nm with a POLAR star Optima microplate reader (BMG LABTECH GmbH, Germany). To assess the MBCs of the control and fermented samples, the MIC and higher concentrations were plated in

MH agar, followed by a 24-h incubation. The negative control was sterile MH broth, and MBC was calculated according to AATCC 100 as shown in Eq. (1):

$$R(\%) = \frac{A - B}{A} \times 100, \quad (1)$$

where A is the total number of bacteria, B is the number of bacteria according to A , and $R(\%)$ is the percent reduction. Each experiment was performed in triplicate, and values are presented as mean $\pm$ SEM.

Antioxidant activity

The antioxidant potentials of the unfermented PSP powder (control) and fermented PSP powders were evaluated by assessing 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging and 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) (ABTS) radical scavenging according to Hu et al. (2004), Virtanen et al. (2007) and Oh et al. (2017).

DPPH radical scavenging activity

DPPH free-radical scavenging activity of unfermented PSP powder (control) and fermented PSP powders was assessed by suspending 10 mg/mL of each fermented and control sample in dimethyl sulfoxide (DMSO) to create stock solutions. The synthetic standard of antioxidant ascorbic acid (10 mg/mL) was prepared in methanol. Dilutions were prepared from the stocks to attain concentrations ranging from 3.12 to 1600 μ g/mL. Diluted solutions (100 μ L) were mixed with 100 μ L of freshly prepared 0.20 mol/L DPPH-methanol solution, vortexed, and kept in the dark at room temperature for 30 min for DPPH radical scavenging to occur. The absorbance of the solutions was then measured using a UV-Vis spectrophotometer at 517 nm. Percentage inhibition of free-radical DPPH was calculated as follows:

$$\text{Inhibition}(\%) = [(A_{\text{blank}} - A_{\text{sample}})/A_{\text{blank}}] \times 100, \quad (2)$$

where A_{blank} is the absorbance of the control reaction (containing all reagents except the test compound), and A_{sample} is the absorbance of the test compound.

ABTS radical cation (ABTS^{•+}) scavenging activity

ABTS^{•+} scavenging activity of unfermented PSP powder (control) and fermented PSP powder was measured by addition of 100 μ L of ABTS^{•+} solution to 100 μ L of fermented samples, control samples, and both standards (3.12–400 μ g/mL). The resultant decrease in absorbance at 734 nm was monitored. The ability to scavenge ABTS^{•+} was calculated using Eq. (2).

Cell viability assay

Cytotoxicity of the unfermented PSP powder (control) and fermented PSP powders was determined using the resazurin assay as described by Coates et al. (2007) and Brown et al. (2012). Briefly, clean coverslips were placed on the bottom of 24-well tissue culture plates. Then, 1×10^4 cells (primary human dermal fibroblasts (HDFs)) were seeded per well in Dulbecco's modified eagle medium (DMEM) supplemented with fetal bovine serum, and an appropriate amount of antibiotic was added, followed by incubation in a 95% air/5% CO₂ atmosphere at 37 °C for 24 h. After incubation, DMEM was removed, cells were washed with fresh PBS saline, and different concentrations (16, 32, and 80 μ g/mL) of each fermented sample or control sample were added, followed by 24 and 72 h incubations. After the incubation period, 600 μ L of resazurin solution was added to each well for 2 h. Then, 200 μ L of each reduced solution was transferred to a 96-well plate to measure fluorescence intensity using a plate reader ($\lambda_{\text{ex}} = 544$ nm and $\lambda_{\text{em}} = 590$ nm). Viable cells (%) were calculated according to the following equation:

$$\text{Viability}(\%) = 100 \text{ Absorption}_{\text{test}} / \text{Absorption}_{\text{control}}. \quad (3)$$

Statistical analysis

All data are expressed as mean $\pm$ standard error of the mean (SEM). All experiments were performed in biological triplicates (on three separate days) with three technical replicates per biological replicate.

Results and discussion

Tang et al. (2015) and Sugata et al. (2015) compared different colored sweet potatoes (white, yellow, orange, light purple, and deep purple) and reported that purple sweet potato species had a higher anthocyanin content and antioxidant capacity than the other color types. The anthocyanin content of purple sweet potato is due to the presence of several non-, mono-, and diacylated glucosides of yaidin and peonidin (Montilla et al. 2010). Purple sweet potatoes are outstanding sources of anthocyanin, β -carotene, and other color-related phytonutrients (Ruttarattanamongkol et al. 2016) reported that, under acidic conditions, purple sweet potato yields more starch than under neutral or basic conditions; therefore, we conducted our study using an acidic pH to increase the availability of starch as a carbon source for the probiotic bacteria. Purple-fleshed sweet potatoes are an excellent source of nutrients and natural health-promoting compounds, such as carotenoids, anthocyanin, polyphenols, ascorbic acid, and dietary fiber (Ruttarattanamongkol et al. 2016). These phytochemical compounds, especially polyphenols, have high free-radical scavenging activity, intermediate antioxidant

activity, and are antimutagenic (Teow et al. 2007; Ruttaratnamongkol et al. 2016). Pourramezan et al. (2018) fermented probiotics that showed maximum antibacterial and antioxidant activity in mid-exponential phase and stationary growth phase. In this study, the probiotic characteristics of *L. brevis* were confirmed according to Plessas et al. (2017). There are two stages of fermentation: photobiological fermentation when the sugar present in the fruit is released and utilization of sugar during fermentation, resulting in complete conversion of sugars and other phytochemicals into bioactive compounds under different light sources.

FT-IR

Samples of unfermented PSP powder (control) and fermented PSP powders were subjected to FT-IR analysis to determine functional groups (Fig. 2) (line from top to bottom). Spectra (400–4000 cm^{-1}) were interpreted using the guidelines of Namiesnik et al. (2014) and Oh et al. (2017). Results were compared among samples grown under different light conditions and the control extract. Compared to the control extract, new peaks at 3200–3000, 1400–1800, and 400–1100 cm^{-1} were present in samples obtained after *L. brevis*-mediated fermentation under sunlight, white LED light, red LED light, and green LED light, respectively. The peak around 3420 cm^{-1} seen in all samples was assigned to hydroxyl group stretching vibrations, and the broad band was attributed to complex vibration stretches of intermolecular hydroxyl groups. Peaks at around 2930 and 1640 cm^{-1} were associated with CH₂ stretching vibrations and deformation vibrations of the hydroxyl groups in water, respectively. Weak bands at 1370 and 1420 cm^{-1} were attributed to the twisting and bending of CH₂ (Zheng et al. 2016). The

prominent broad peak at 3200–3000 cm^{-1} was attributed to the phenolic OH group and CO stretching band, while that at 2800–2900 cm^{-1} was attributed to strong stretching vibrations of –OH functional groups and the C–OH stretching/bending of primary or aromatic alcohols. The peaks at 1400–1700 cm^{-1} may have been caused by the stretching vibrations of alkene groups (–C=C–), carboxylic acid, C=O stretching phenyl ring amino acid-1, or –OH phenolic bending and carbonyl groups. We attributed the absorbance at 1424 cm^{-1} to ether linkages or –C–O– groups. The common band at 1020–1050 cm^{-1} was due to aromatic bending and stretching. The peaks in each extract sample in the range of 3300–3000 cm^{-1} suggested the presence of pectin, gallic acid, hesperidin, and tannic acid (Fig. 2). The peaks at 2925 and 2847 cm^{-1} could represent aromatic carboxylic acids and hydroxyl groups. Weak stretching at 2340 cm^{-1} was attributed to the presence of an alkyne group, while the weak signal at 1460 cm^{-1} was attributed to nitro groups. The presence of aromatic primary amine groups, which result from fermentation by probiotic microorganisms, implied the presence of bacterial proteins in the fermented extract, which could have contributed to the antibacterial nature of the fermented samples (Vaithilingam et al. 2016). Dark and blue LED light did not produce fermented extracts with any interesting peaks compared to the control sample (Fig. 2).

Antimicrobial activity

Fermented PSP powders and unfermented powder (control) inhibited the growth of the skin bacteria *P. acne* and *S. epidermidis* (Table 1). *L. brevis* fermentation of PSP powder under white LED light, sunlight, and blue and green LED light produced fermented extracts that had excellent activity against *P. acne*, with ZoI values of 1.9 ± 1.80 , 1.5 ± 1.68 , 1.3 ± 1.43 , and 0.7 ± 1.93 mm, respectively. ZoI values for these extracts against *S. epidermidis* were 1.9 ± 0.52 , 1.8 ± 1.83 , 1.9 ± 0.83 , and 1.1 ± 1.36 mm, respectively, at a concentration of 200 mg/0.5 mL (Table 1). *B. amyloliquefaciens*-fermented extracts also showed moderate activity against both species of skin bacteria (Table 1). Notably, white LED light and sunlight exposure during fermentation resulted in production of antibacterial compounds that can be used in cosmetics. High concentrations of the control extract had smaller ZoIs for *P. acne* and *S. epidermidis* than those obtained under light fermentation, demonstrating that probiotic organisms can convert phytochemicals into biologically important peptides, exopolysaccharides, secondary metabolites, and other organic compounds (Todorov 2008). MIC and MBC values are displayed in Fig. 3a, b and corroborate those found in well diffusion screening; there were no significant differences in MIC or MBC for the two types of skin bacteria. Significantly lower MIC

Fig. 2 FTIR spectra of non-fermented powder of purple sweet potato and purple sweet potato powder fermented with *L. brevis* under various light sources

Table 1 Well diffusion assay (ZOI mm) of probiotic-mediated fermented PSP powder along with LED lights samples against skin bacteria

Probiotic bacteria	Fermented extract and control (mg/0.5 mL)	Control	<i>P. acne</i>					<i>S. epidermidis</i>						
			LED lights					LED lights						
			Green	Red	Blue	White	Sun light	Dark	Green	Red	Blue	White	Sun light	Dark
<i>L. brevis</i>	25	–	–	–	–	–	–	–	–	–	–	–	–	
	50	–	–	–	–	–	–	–	–	–	–	–	–	
	100	0.4±0.85	–	0.6±2.42	1.2±0.66	1.8±0.71	1.1±0.89	–	–	0.9±0.44	1.3±1.18	1.6±1.52	1.6±1.63	–
	200	0.8±1.34	0.6±1.62	1.5±1.23	1.4±1.32	1.9±1.80	1.2±1.26	0.3±1.46	1.1±1.36	0.5±1.12	1.8±0.83	1.6±0.52	1.5±1.83	0.5±1.37

The values are presented as average value ± standard deviation

concentrations were obtained for extracts fermented under white LED light, sunlight, and green LED light than the control sample. Figure 3a shows that white LED light, sunlight, and green LED light-fermented extracts at concentrations of 80 and 160 mg/mL had lower MIC values and lower MBC (Fig. 3b) percentages for *P. acne* and *S. epidermidis* than did the control extract.

DPPH and ABTS radical (ABTS⁺) scavenging activity

DPPH and ABTS radical scavenging abilities of the fermented PSP powders and unfermented PSP powder (control) are shown in Fig. 4a, b. DPPH free-radical scavenging activity of extract obtained from *L. brevis* fermentation under white LED light, red LED light, sunlight, and blue LED light increased in a dose-dependent manner (Fig. 4a). Furthermore, white LED light, blue LED light, sunlight, and red LED light-fermented extracts had highest scavenging activity at 1600 µg/mL with IC₅₀ values of 106.91 ± 4.46, 121.65 ± 2.32, 154.62 ± 2.27/mL, and 212.39 ± 2.18 µg/mL, respectively. In the concentration range of 3.125–100 µg/mL, control PSP extract fermented under different light sources had lower scavenging activity than the reference ascorbic acid standard (Fig. 4a). Our results corroborate earlier reports that PSPs have a high total polyphenol content and antioxidant activity (Teow et al. 2007; Lee et al. 2016).

ABTS⁺ scavenging activity of all extracts obtained from probiotic fermentation with *L. brevis* under different light sources increased in a dose-dependent manner over the concentration range of 3.125–400 µg/mL (Fig. 4b). Sunlight, white LED light, blue LED light, red LED light, green LED light, and dark-fermented extracts displayed strong scavenging activity at the maximum concentration (400 µg/mL). The IC₅₀ values for *L. brevis*-fermented extracts were as follows: sunlight, 63.21 ± 0.06 µg/mL; white LED light, 178.24 ± 0.16 µg/mL; blue LED light, 1114.06 ± 0.02 µg/mL; red LED light, 108.64 ± 0.23 µg/mL; green LED light, 99.92 ± 0.11 µg/mL; and dark, 68.92 ± 0.05 µg/mL. Ascorbic acid was used as the positive control and had the highest scavenging activity [(52.84 ± 0.06)% at 400 µg/mL with an IC₅₀ value of 12.26 ± 1.41 µg/mL]. Control PSP extract (IC₅₀ of 234.72 ± 1.15 µg/mL) showed a gradual concentration-dependent decrease in activity (Fig. 4b). The main constituents of purple sweet potatoes are anthocyanins [cyanidin-3-O-glucoside (Cy3G) and peonidin-3,5-O-diglucoside], which have antioxidant properties and are responsible for the purple color of the tuber. Cy3G has DNA-RSC, gastro-protective, anti-inflammatory, anti-thrombotic, antibacterial, and chemopreventive activity and can regulate epigenetics and be used to treat age-related diseases, type 2 diabetes, cardiovascular disease, metabolic syndrome, and oral cancer (Lim et al. 2013).

Fig. 3 MIC and MBC values of unfermented purple sweet potato powder and purple sweet potato powder fermented with probiotic organisms under various light sources

Fig. 4 Ability of purple sweet potato powder fermented with probiotic organisms under various light conditions compared to the control extract or ascorbic acid to scavenge **a** DPPH radicals (3.125–1600 $\mu\text{g/mL}$)

and **b** ABTS (3.125–400 $\mu\text{g/mL}$). All data are expressed as mean $\pm$ SEM, $n=2$. IC_{50} concentrations were calculated using nonlinear regression in Graphpad Prism version 5.1.0

Cytotoxic activity

MTT assay

Figure 5a, b show the effects of different concentrations of all extracts on human dermal fibroblasts (HDFs) cultured for 24 and 72 h. A low degree of confluency (10%) of HDFs cells was noticed. All obtained samples had significantly lower cytotoxicity than the control and reduced cell viability by 8% (red LED light extract), 7% (blue LED light extract), and 6% (dark extract) at 80 $\mu\text{g/mL}$ at 24 h (Fig. 5a) and 72 h (Fig. 5b). White LED light, blue LED light, and sunlight-fermented PSP extract samples had milder cytotoxicity than the control

extract (Fig. 5a). A longer exposure time (up to 72 h) resulted in a significant reduction in cell viability (10% or more of the control) for extracts fermented under all light sources (Fig. 5b). Together, these results suggest that the extracts had negligible cytotoxicity for exposure times up to 72 h. However, when the concentration of extract was increased to 80 $\mu\text{g/mL}$, a significant reduction in cell viability was observed for more confluent HDFs.

Fig. 5 Effects of purple sweet potato powder fermented by *L. brevis* under various light conditions and control samples on human dermal fibroblasts cells after **a** 24 h and **b** 72 h of incubation

Conclusions

In this study, we investigated the antibacterial, antioxidant, and cytotoxic activities of PSP powders fermented by *L. brevis* under different color LED lights, sunlight, and darkness and investigated functional groups of the fermented powders using FT-IR spectra. PSP powder fermented under blue or white LED light or sunlight had significant antibacterial, antioxidant, and cytotoxic activity. Together, our findings indicate that PSP powder can be fermented by probiotic bacteria using different light sources to obtain natural antibacterial and antioxidant agents that have applications in the medical, health, and cosmetic industries. In-depth studies are needed to determine the mechanisms by which light induces the production of various compounds during fermentation.

Acknowledgements This work was supported by Korea Institute for Ministry of SMEs and Startup (MSS) through the Industrial Cooperative R&D Program (R0006163). This research was also supported by “Research Base Construction Fund Support Program” funded by Chonbuk National University in 2018.

Compliance with ethical standards

Conflict of interest We declare that we have no conflicts of interest.

References

- Brown EM, McDougall GJ, Stewart D, Pereira-Caro G, González-Barrio R, Allsopp P, Magee P, Crozier A, Rowland I, Gill CI (2012) Persistence of anticancer activity in berry extracts after simulated gastrointestinal digestion and colonic fermentation. *PLoS One* 7:49740
- Coates EM, Popa G, Gill CI, McCann MJ, McDougall GJ, Stewart D, Rowland I (2007) Colon-available raspberry polyphenols exhibit anti-cancer effects on in vitro models of colon cancer. *J Carcinog* 6:4
- Conlon MA, Bird AR (2014) The impact of diet and lifestyle on gut microbiota and human health. *Nutrients* 7:17–44
- Esatbeyoglu T, Rodriguez-Werner M, Schlosser A, Winterhalter P, Rimbach G (2017) Fractionation, enzyme inhibitory and cellular antioxidant activity of bioactives from purple sweet potato (*Ipomoea batatas*). *Food Chem* 221:447–456
- Hai T, Ahlers H, Gorenflo V, Steinbuechel A (2000) Axenic cultivation of an oxygenic phototrophic bacteria, cyano bacteria, and microalgae in a new closed tubular glass photobioreactor. *Appl Microbiol Biotechnol* 53:383–389
- Halib N, Perrone F, Cemazar M, Dapas B, Farra R, Abrami M, Chi-arappa G, Forte G, Zancanati F, Pozzato G, Murena L, Fiotti N, Lapasin R, Cansolino L, Grassi G, Grassi M (2017) Potential applications of nanocellulose-containing materials in the biomedical field. *Materials (Basel)* 10:E977
- Hu CC, Hsiao CH, Huang SY, Fu SH, Lai CC, Hong TM, Chen HH, Lu FJ (2004) Antioxidant activity of fermented soybean extract. *J Agric Food Chem* 52:5735–5739

- Hussain MS, Fareed S, Saba Ansari M, Rahman A, Ahmad IZ, Saeed M (2012) Current approaches toward production of secondary plant metabolites. *J Pharm Bioallied Sci* 4:10
- Ige OO, Umoru LE, Aribio S (2012) Natural products: a minefield of biomaterials. *ISRN Mater Sci* 2012:983062. <https://doi.org/10.5402/2012/983062>
- Konczak-Islam S, Okuno M, Yoshimoto O, Yamakawa O (2003) Composition of phenolics and anthocyanins in a sweetpotato cell suspension culture. *Biochem Eng J* 14:155–161
- Lee SH, Oh SH, Hwang IG, Kim HY, Woo KS, Woo SH, Kim HS, Lee J, Sang Jeong H (2016) Antioxidant contents and antioxidant activities of white and colored potatoes (*Solanum tuberosum* L.). *Prev Nutr Food Sci* 21:110–116
- Lim S, Xu J, Kim J, Chen T-Y, Su X, Standard J, Carey E, Griffin J, Herndon B, Katz B, Tomich J, Wang W (2013) Role of anthocyanin-enriched purple-fleshed sweet potato P40 in colorectal cancer prevention. *Mol Nutr Food Res* 57:1908–1917
- Limon RI, Penas E, Torino MI, Martínez-Villaluenga C, Duenas M, Frias J (2015) Fermentation enhances the content of bioactive compounds in kidney bean extracts. *Food Chem* 172:343–352
- Montilla EC, Hillebrand S, Butschbach D, Baldermann S, Watanabe N, Winterhalter P (2010) Preparative isolation of anthocyanins from japanese purple sweet potato (*Ipomoea batatas* L.). Varieties by high-speed counter current chromatography. *J Agric Food Chem* 58:9899–9904
- Nagamine R, Ueno S, Tsubata M, Yamaguchi K, Takagaki K, Hira T, Hara H, Tsuda T (2014) Dietary sweet potato (*Ipomoea batatas* L.) leaf extract attenuates hyperglycaemia by enhancing the secretion of glucagon-like peptide-1 (GLP-1). *Food Funct* 5:2309–2316
- Namiesnik J, Vearasilp K, Leontowicz H, Leontowicz M, Ham K-S, Kang S-G, Park Y-K, Avila PA, Toledo F, Gorinstein S (2014) Comparative assessment of two extraction procedures for determination of bioactive compounds in some berries used for daily food consumption. *IJFST* 49:337–346
- Oh BT, Jeong SY, Velmurugan P, Park JH, Jeong DY (2017) Probiotic-mediated blueberry (*Vaccinium corymbosum* L.) fruit fermentation to yield functionalized products for augmented antibacterial and antioxidant activity. *J Biosci Bioeng* 124:542–550
- Plessas S, Nouska C, Karapetsas A, Kazakos S, Alexopoulos A, Mantzourani I, Chondrou P, Fournomiti M, Galanis A, Bezirtzoglou E (2017) Isolation, characterization and evaluation of the probiotic potential of a novel *Lacto bacillus* strain isolated from Feta-type cheese. *Food Chem* 1:102–108
- Pourramezan Z, KasraKermanshahi R, Oloomi M, Aliahmadi A, Rezadoost H (2018) In vitro study of antioxidant and antibacterial activities of *Lacto bacillus* probiotic spp. *Folia Microbiol* 63:31–42
- Ruttarattanamongkol K, Chittrakorn S, Weerawatanakorn M, Dangpium N (2016) Effect of drying conditions on properties, pigments and antioxidant activity retentions of pretreated orange and purple-fleshed sweet potato flours. *JFST* 53:1811–1822
- Sugata M, Lin CY, Shih YC (2015) Anti-inflammatory and anticancer activities of taiwanese purple-fleshed sweet potatoes (*Ipomoea batatas* L. Lam) extracts. *Biomed Res Int* 2015:768093. <https://doi.org/10.1155/2015/768093>
- Surendra Babu A, Parimalavalli R, Jagannadham K, Sudhakara Rao J (2015) Chemical and structural properties of sweet potato starch treated with organic and inorganic acid. *JFST* 52:5745–5753
- Tang Y, Cai W, Xu B (2015) Profiles of phenolics, carotenoids and antioxidative capacities of thermal processed white, yellow, orange and purple sweet potatoes grown in Guilin, China. *Food Sci Hum Wellness* 4:123–132
- Teow CC, Truong VD, McFeeters RF, Thompson RL, Pecota KV, Yencho GC (2007) Antioxidant activities, phenolic and β -carotene contents of sweet potato genotypes with varying flesh colours. *Food Chem* 103:829–838
- Todorov SD (2008) Bacteriocin production by *Lactobacillus plantarum* AMA-K isolated from Amasi, a Zimbabwean fermented milk product and study of adsorption of bacteriocin AMA-K to *Listeria* spp. *Braz J Microbiol* 38:178–187
- Trung PTB, Ngoc LBB, Hoa PN, Tien NNT, Van Hung P (2017) Impact of heat-moisture and annealing treatments on physicochemical properties and digestibility of starches from different colored sweet potato varieties. *Int J Biol Macromol* 105:1071–1078
- Vaithilingam M, Chandrasekaran S, Mehra A, Prakash S, Agarwal A, Ethiraj S, Vaithiyanathan S (2016) Fermentation of beet juice using lactic acid bacteria and its cytotoxic activity against human liver cancer cell lines HepG2. *Curr Bioact Compd* 12:258–263
- Velmurugan P, Kim JI, Kim K, Park JH, Lee KJ, Chang WS, Park YJ, Cho M, Oh BT (2017) Extraction of natural colorant from purple sweet potato and dyeing of fabrics with silver nanoparticles for augmented antibacterial activity against skin pathogens. *J Photochem Photobiol B* 173:571–579
- Virtanen T, Pihlanto A, Akkanen S, Korhonen H (2007) Development of antioxidant activity in milk whey during fermentation with lactic acid bacteria. *J Appl Microbiol* 102:106–115
- Yan D, Wang C, Zhou J, Liu Y, Yang M, Xing J (2013) Construction and fermentation control of reductive TCA pathway for malic acid production in *Saccharomyces cerevisiae*. *Chin J Biotechnol* 29:1484–1493
- Zhang ZC, Su GH, Luo CL, Pang YL, Wang L, Li X, Wen JH, Zhang JL (2015) Effects of anthocyanins from purple sweet potato (*Ipomoea batatas* L.) on the serum uric acid level and xanthine oxidase activity in hyperuricemic mice. *Food Funct* 6:3045–3055
- Zheng Y, Wang Q, Li B, Lin L, Tundis R, Loizzo MR, Zheng B, Xiao J (2016) Characterization and prebiotic effect of the resistant starch from purple sweet potato. *Molecules* 21:932–943