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Fermented pickle production from water hyacinth (*Eichhornia crassipes* Solms) stem

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Abstract

Water hyacinth (*Eichhornia crassipes* Solms) is a free-floating aquatic species widely distributed on rivers, canals and estuaries. It propagated quickly and extensively in a short period. This caused some obstacles for river traffic. This plant was utilized for the production of handicrafts, fertilizer, animal feed, and biofuel in the agro-industry. People also consumed the young stem of this plant as a natural vegetable food in cuisine due to its palatable taste. Pickling was well-known as one of the most ancient gastronomic professions to store food under acidic conditions for a long period of time in an ambient environment. This research evaluated the pickle production from the young stems of water hyacinth. Different technical parameters of the pickling process such as effect starter culture strains (*Lactobacillus delbrueckii, Lactobacillus plantarum, Lactobacillus acidophilus* and *Saccharomyces cerevisiae*) with different inoculum ratios (5-25 mL of 10^9 CFU/mL starter culture), brine solutions (250 ppm of potassium chloride, calcium chloride, calcium acetate, magnesium chloride, aluminum chloride combined with 5% of sodium chloride), sugar content (2-4%) and fermentation time (0-10 days) were thoroughly examined. Firmness (N), total acidity (%), total phenolic content (mg GAE/100 g dry weight), total antioxidant capacity (mg AAE/g dry weight) and sensory score were measured to define the optimal species of starter culture, ratio of starter culture, brine solution, sugar content and fermentation time. Results showed that young water hyacinth stems should be fermented with 20 mL of 10^9 CFU/mL *L. plantarum* with 5% sodium chloride, combined with 250 ppm of calcium chloride, 3% sugar supplementation and 6 days of fermentation. Pickle of young water hyacinth stem maintained the highest texture firmness (11.86±0.03 N), total acidity (1.50±0.01%), total phenolic content (61.07±0.04 mg GAE/100 g dry weight), total antioxidant capacity (7.79±0.02 mg AAE/g dry weight) and sensory score (8.91±0.03). The added value of water hyacinth could be highly exploited from this research.

1. Introduction

Water hyacinth (*Eichhornia crassipes* Solms) was a popular aquatic plant found in tropical and subtropical areas. It contained numerous bioactive components like phenolic, flavonoid, saponin, sterol, terpenoid, fatty acid, tannin, and alkaloid (Fitsum *et al*., 2025). These elements revealed different therapeutic attributes such as antioxidant, antimicrobial, antitumor, antidepressant antidepressant (Ben Bakrim *et al*., 2022). This plant was widely exploited for various purposes as biofuel (Shanab *et al*., 2018), biofertilizer (Manyuchi *et al*., 2019), animal feed (Rufchaei *et al*., 2020), wastewater treatment (Mustafa and Hayder, 2021), phytoremediation (El-Chaghaby *et al*., 2022), and handicraft (Ifa *et al*., 2023). Heavy metals that exist in wastewater can be eliminated effectively by bioabsorption (Mustafa and Hayder, 2021). In daily cuisine, consumers use the young stem of water hyacinth as a natural edible vegetable in a hot pot with fermented fish.

Pickling was one of the effective preservation techniques to preserve vegetables for long-term consumption without refrigeration. Pickling not only prolonged the product's shelf-life but also influenced the sensory attributes of the pickle (Tadak *et al*., 2025). There were two pickling categories, including unfermented and fermented pickles (Sudhanshu *et al*., 2020). Unfermented pickle could be performed by soaking of raw material in either salt or vinegar. In

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fermented pickles, there were sour and sweet methods. Sour pickling was prepared by soaking vegetables in brine, while sweet pickling was performed with the support of sugar (Sudhanshu *et al*., 2020). Lactic acid bacteria played an important role in fermented pickles, directly influencing to nutritional quality and hygiene safety of the pickled product with numerous health advantages (Sanlier *et al*., 2019). Lactic acid bacteria revealed diversified probiotic characteristics like self-defence against infectious risk in the gastrointestinal line, resistance to urogenital invasion, tumor prevention, digestive enhancement, and obesity depression (Liong and Shah, 2005). Lactic acid bacteria are involved in the lactic fermentation to release a distinctive flavor and degenerate mycotoxin (Sudhanshu *et al*., 2020). Plentiful amounts of nourishments, functional elements and antioxidants could be preserved and restored in the fermented pickles (Rajesh *et al*. 2010; Sayin and Alkan, 2015). Lactic acid bacteria assured the prolonged stability, refresh-flavor without artificial additives (Zhang *et al*., 2019). *Lactobacillus* species were commonly used as versatile starter cultures in fermented pickling (Yousefi *et al*., 2025).

Not many studies mentioned the exploitation of young stems of water hyacinth in pickle form. In the current study, the effect of different technical parameters affecting to physicochemical and phytochemical attributes of pickled water hyacinth stem was examined.

2. Materials and methods

2.1 Materials

Young water hyacinth stems were collected on the local river in Phu Loi district, Can Tho province, Vietnam. Starter cultures of *Lb. delbrueckii* (White Labs PurePitch™, USA*), L. plantarum* (WHC Lab, Ireland), *Lb. acidophilus* (Mitushi Biopharma, India) and *Saccharomyces cerevisiae* (Sigma Aldrich, Steinheim, Germany) were commercially purchased. Chemical reagents like sodium hydroxide, potassium chloride, calcium chloride, calcium acetate, magnesium chloride, aluminum chloride, ethanol, Folin-Ciocalteu reagent, sodium carbonate, sulfuric acid, sodium phosphate, ammonium molybdate were all of analytical grade and purchased from Fluka Chemical (USA). Sodium chloride and refined sugar (in food grade) were bought from a local grocery store.

2.2 Methodology

Young water hyacinth stems were manually washed under tap water to remove dirt and foreign segments. These stems were blanched in hot water at 100^{o}C for 5 s and then rapidly dipped in ice water. Approximately 500 g of blanched young water hyacinth stems were inserted into each plastic container with 600 mL of 5% sodium chloride solution. Each container was inoculated with different starter cultures, including *Lactobacilus delbrueckii, Lactobacilus plantarum, Lactobacilus acidophilus* and *Saccharomyces cerevisiae* with different inoculum ratios (5, 10, 15, 20, 25 mL of 10^9 CFU/mL starter culture). Different brine solutions of calcium chloride, calcium acetate, magnesium chloride, aluminum chloride (at a concentration 250 ppm) were incorporated into 5% sodium chloride solution. The effect of different sugar contents (2-4%) was also examined. Containers were tightly covered by a cap and left at ambient temperature (30±0.5^{o}C). The fermentation process took place in various durations (2-10 days). Firmness (N), total acidity (%), total phenolic content (mg GAE/100 g dry weight), total antioxidant capacity (mg AAE/g dry weight) were measured to define the optimal species of starter culture, ratio of starter culture, brine solution, sugar content and fermentation time.

2.2.1 Firmness

Firmness (N) was determined by texture analyzer (model: TA XT-plus, Stable Micro Systems, UK). Equipment prepared with a 2 mm diameter nose needle that pricked via 10 mm of mesocarp at a velocity of 10 mm/s. The sample was put laterally by the needle to keep a comparable length from the endocarp paradigms (Lopez-Lopez *et al*., 2019).

2.2.2 Total acidity

Total acidity (%) was measured following Liu's procedure. Ten grams of ground sample was mixed with 100 mL of distilled water, submerging for 15 min, sieving, and titrating with NaOH (0.1 M) to pH 8.0 (Liu *et al*., 2019).

2.2.3 Total phenolic content

Total phenolic content or TPC (mg GAE/100 g dry weight) was measured by Folin-Ciocalteu reagent utilizing a colourimetric protocol (Zainol *et al*., 2018). Approximately 10 mL of extract was mixed with 90% ethanol (v/v) in a 25 mL test tube and centrifuged at 3,500 rpm for 3 min. Aliquot 4 mL of the supernatant was diluted with 5.0 mL Folin-Ciocalteu reagent 8% (w/v). The mixture was left for 5 min and then mixed with 1 mL of Na_2CO_3 (10% w/v). Reaction occurred for 30 min in a dark place, and the absorbance was recorded at 765 nm by a UV spectrophotometer (model: UV-1800, Shimazu, Japan).

2.2.4 Total antioxidant capacity

The total antioxidant capacity or TAC (mg AAE/g dry weight) was analyzed following the protocol

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conducted by Prieto *et al*. (1999). Five mL of extract was diluted with 5 mL of mixture (1.5 M sulfuric acid, 70 mM sodium phosphate, and 10 mM ammonium molybdate). The suspension was incubated at 90°C for 60 min. Samples were cooled to ambient temperature, ready for reading the absorption by ELISA Reader (model: MPR-H200BN, Infitek, UK) at 593 nm. Results were calculated as mg ascorbic acid equivalent per gram dry weight.

2.2.5 Sensory evaluation

Overall acceptance of grass jelly was evaluated by a group of 11 qualified specialists (aged 24-30 years old) using a 9-point Hedonic scale where scale 9 represented like extremely and 1 dislike extremely. They evaluated samples based on aspect, flavour and taste which were expressed as overall acceptance on scale 1-9. The organoleptic evaluation was randomized on samples branded with incidentally two-digit codes.

2.3 Statistical analysis

The experiments were performed in triplicate with different groups of samples. Variance and Duncan's multiple-range tests were utilized to statistically analyze all data. The results were presented with substantial letters as mean±standard deviation. Differences between means were noted as significant when $p < 0.05$. Statistical analysis was performed by the Statgraphics Centurion version XVI.

3. Results and discussion

3.1 Effect of starter culture strains on physicochemical, phytochemical and sensory characteristics of pickled water hyacinth stem

Table 1 shows the effect of different starter culture strains (*Lb. delbrueckii, L. plantarum, Lb. acidophilus* and *Saccharomyces cerevisiae*) in the same inoculum ratio (5 mL of 10^9 CFU/mL starter culture), 5% of sodium chloride solution, 2% of sugar in 2 days of fermentation on the physicochemical, phytochemical and organoleptic attributes of pickled young water hyacinth stem. Results revealed that *L. plantarum* supported for lactic acid fermentation to maintain the highest values of texture firmness (8.19±0.03N), total acidity (0.62±0.00%), total phenolic content (39.70±0.04 mg GAE/100 g dry weight), total antioxidant capacity (4.22±0.01 mg AAE/g dry weight) and overall acceptance (5.04±0.05) of pickle sample. Lactic acid bacteria involved in the biosynthesis pathway to accumulate distinctive aroma components indirectly contribute to firmness modification and extended durability of pickles (Leroy and De Vuyst, 2004). Lactic acid bacteria also competed with harmful pathogens and spoilage microorganisms to prevent their outbreak in pickle (El Sheikha and Hu, 2020). Incorporation of starter cultures was very important for pickling fermentation. Caper fruits fermented by the predominant *Lb. plantarum* with a quick acidification resulted in pH < 4.5 and high internal temperature (40°C), limiting the growth and proliferation of harmful *Leuconostoc* sp. (Di Cagno and Coda, 2014). Complex starter culture in pickling induced faster acidity accumulation compared to mono culture and natural strains (Ceren and Hatice, 2018). Fermentation time was reduced significantly to 11 –12 days at 17°C at a low brine concentration (4.7%, w/v), shorter than 35 days in a non-cultured batch (Sudhanshu *et al*., 2020). *Saccharomyces cerevisiae* and *Lb. plantarum* could endure initial high brine content during the pickling process (Sudhanshu *et al*., 2020).

3.2 Effect of starter culture ratios on physicochemical, phytochemical and sensory characteristics of pickled water hyacinth stem

Physicochemical, phytochemical and organoleptic attributes of pickled young water hyacinth stem were significantly different by the starter culture ratio of *Lb. plantarum* (5-25 mL of 10^9 CFU/mL *Lb. plantarum*). There was an increasing trend of firmness, acidity, total phenolic content, total antioxidant capacity and sensory score from 5-25 mL of 10^9 CFU/mL *Lb. plantarum*. There was no significant difference in quality attributes at 20 and 25 mL of 10^9 CFU/mL *Lb. plantarum* (Table 2). Therefore, 20 mL of 10^9 CFU/mL *Lb. plantarum* was

Table 1. Effect of starter culture strains on physicochemical, phytochemical and sensory characteristics of pickled young water hyacinth stem.

Variables	Starter cultures				
	Control	*Lb. delbrueckii*	*L. plantarum*	*Lb. acidophilus*	*Saccharomyces cerevisiae*
Firmness (N)	4.57±0.04^{c}	6.13±0.02^{b}	8.19±0.03^{a}	5.77±0.02^{bc}	7.35±0.06^{ab}
Acidity (%)	0.30±0.02^{c}	0.48±0.03^{b}	0.62±0.00^{a}	0.37±0.01^{bc}	0.54±0.01^{ab}
TPC (mg GAE/100 g)	21.32±0.06^{c}	31.29±0.01^{b}	39.70±0.04^{a}	27.33±0.05^{bc}	36.05±0.03^{ab}
TAC (mg AAE /g)	1.04±0.03^{c}	3.11±0.07^{b}	4.22±0.01^{a}	2.25±0.03^{bc}	3.86±0.05^{ab}
Overall acceptance	3.08±0.01^{c}	4.12±0.04^{b}	5.04±0.05^{a}	3.65±0.02^{bc}	4.67±0.02^{ab}

Values are presented as mean±SD of three replicates. Values with different superscripts in the same row are statistically significantly different (α = 0.05).

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Table 2. Effect of starter culture ratios on physicochemical, phytochemical and sensory characteristics of pickled young water hyacinth stem.

Variables	Ratios (mL) of 10^9 CFU/mL *L. plantarum*				
	5	10	15	20	25
Firmness (N)	8.19±0.03^{c}	8.57±0.04^{bc}	8.93±0.01^{b}	9.36±0.03^{ab}	9.50±0.04^{a}
Acidity (%)	0.62±0.00^{c}	0.69±0.01^{bc}	0.74±0.03^{b}	0.80±0.02^{ab}	0.86±0.00^{a}
TPC (mg GAE/100 g)	39.70±0.04^{c}	43.17±0.02^{bc}	46.34±0.00^{b}	49.11±0.01^{ab}	53.07±0.03^{a}
TAC (mg AAE /g)	4.22±0.01^{c}	4.65±0.03^{bc}	4.97±0.04^{b}	5.40±0.02^{ab}	5.89±0.01^{a}
Overall acceptance	5.04±0.05^{c}	5.39±0.00^{bc}	5.85±0.01^{b}	6.31±0.00^{ab}	6.74±0.02^{a}

Values are presented as mean±SD of three replicates. Values with different superscripts in the same row are statistically significantly different (α = 0.05).

fixed for further experiments. Starter culture converted hexoses into lactic acid and afterwards to acetic acid (Zaunmuller *et al*., 2006). *Lb. plantarum* was highly valued as an important starter culture to enhance organoleptic attributes of pickles (Cetin, 2011). Young bamboo shoot was pickled by *Lb. plantarum* with high lactic acid and low HCN content (Kumar *et al*., 2017). Mixture of *Lb. plantarum* and *Saccharomyces cerevisiae* enhanced the proximate composition and physicochemical characteristics of pickled cucumber (Behera *et al*., 2018). Total phenolic content (5.80±0.32 µg GAE/g dry weight), total antioxidant capacity (3.38±0.80 mg AAE/g dry weight) in water hyacinth stems were noticed (Rabiepour *et al*., 2025).

3.3 Effect of different brine solutions on physicochemical, phytochemical and sensory characteristics of pickled water hyacinth stem

Softening was one of the most important obstacles in the pickle process. This behavior is related to the demolition of pectin in the middle lamella of vegetable tissue. In the current research, young water hyacinth stem was submerged in different brine solutions, such as potassium chloride, calcium chloride, calcium acetate, magnesium chloride, aluminum chloride at 250 ppm concentration with 5% of sodium chloride. It was easily noticed that the highest values of firmness, total acidity, total phenolic content, total antioxidant capacity and overall acceptance of all samples were obtained by 250 ppm of calcium chloride + 5% of sodium chloride (Table 3). Calcium chloride combined with sodium chloride resulted in a significant difference in firmness and overall acceptance, with minor impact on total acidity, total phenolic content and total antioxidant capacity. It might be due to the reactions between galacturonic acid and the ions (Yousef *et al*., 2025). Salt was considered one of the important factors in the pickling technique as it extracted proximate compositions and moisture out of plant tissue, which were utilized as ingredients, while salt was believed to be a substrate for the proliferation of lactic acid bacteria (Hassan and Sarfraz, 2018). Raw peaches were submerged in 5%–10% brine, softly vibrated and fermented at low temperature for one day to achieve the best pickled quality (Chen *et al*., 2013). *Lb. plantarum* is involved in the pickling of vegetables in the presence of salt solution (8%, w/w) (Li *et al*., 2015).

One major concern in the consumption of pickles was abuse of too much sodium intake, resulting in hypertension and high blood pressure, leading to cardiovascular symptoms (He and Tan, 2024). Calcium chloride was greatly effective in the prohibition of the demethylation of pectins (Hudson, 2007). Ca^{2+} interacted with galacturonans to form a complex limiting de-polymerization by hydrolysis (Buescher *et al*., 2011). Ca^{2+} induced better firmness in the pickling of cucumber (Buescher *et al*., 2011). Ca^{2+} involvement resulted in high acidity at the beginning of pickling favoring the transformation of sugar into lactic acid (Perez-Diaz *et*

Table 3. Effect of brine solutions (250 ppm of potassium chloride, calcium chloride, calcium acetate, magnesium chloride, aluminum chloride) + 5% of sodium chloride on physicochemical, phytochemical and sensory characteristics of pickled young water hyacinth stem.

Variables	5% of sodium chloride + 250 ppm of				
	Potassium chloride	Calcium chloride	Calcium acetate	Magnesium chloride	Aluminum chloride
Firmness (N)	9.78±0.01^{c}	11.24±0.00^{a}	10.84±0.02^{ab}	10.47±0.04^{b}	9.96±0.02^{bc}
Acidity (%)	0.88±0.03^{b}	0.98±0.01^{a}	0.97±0.04^{ab}	0.93±0.00^{ab}	0.90±0.04^{b}
TPC (mg GAE/100 g)	51.46±0.02^{b}	51.97±0.04^{a}	51.84±0.03^{ab}	51.78±0.03^{b}	51.69±0.00^{b}
TAC (mg AAE /g)	5.87±0.04^{b}	6.23±0.02^{a}	6.09±0.00^{ab}	6.01±0.02^{ab}	5.96±0.03^{b}
Overall acceptance	6.60±0.03^{c}	8.02±0.00^{a}	7.79±0.02^{ab}	7.35±0.03^{b}	6.98±0.01^{bc}

Values are presented as mean±SD of three replicates. Values with different superscripts in the same row are statistically significantly different (α = 0.05).

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al., 2018). High content of sodium chloride greatly decreased total acidity and directly prevented proliferation of lactic acid bacteria (Zheng *et al*., 2020). Sodium chloride 3.5% combined with manganese chloride 30 mM was optimal for Kohlrabi pickling production (Hien *et al*., 2022). Sodium chloride, in conjunction with calcium chloride, effectively controlled texture softening (Yousef *et al*., 2025). This could be explained by the creation of Ca-pectates supporting middle lamella cell wall durability and prevention of decomposition by polygalacturonase. Calcium acetate combined with calcium chloride enabled preservation of hardness and prolonged stability of cucumber pickle (Yousef *et al*., 2025). Al^{3+} interacted with pectin to maintain texture firmness (Yousef *et al*., 2025). Sodium chloride could be replaced by potassium chloride or magnesium chloride with minor modification in the quality properties of pickled apples (Constandache *et al*., 2025).

3.4 Effect of sugar ratio supplementation on physicochemical, phytochemical and sensory characteristics of pickled water hyacinth stem

Sugar supplementation was very important to provide substrate for starter cultures in growth, proliferation and biosynthesis of bioactive metabolites. There was an increasing trend of texture firmness (11.24±0.00 to 12.09±0.01 N), total acidity (0.98±0.01 to 1.27±0.02%), total phenolic content (51.97±0.04 to 58.24±0.00 mg GAE/100 g dry weight), total antioxidant capacity (6.23±0.02 to 7.32±0.03 mg AAE/g dry weight) and overall acceptance (8.02±0.00 to 8.67±0.01) of pickle sample by increasing sugar ratio supplementation from 2.0-3.0%. Over 3.0% of sugar, there was a downward trend of these quality attributes (Table 4). It might be due to the inhibition of *Lb. plantarum* under high osmotic pressure created by high sugar content. A 3.0% sugar incorporation was adequate to receive the best quality attributes of pickled young water hyacinth stems. In the pickling process, sugar was biotransformed to lactic acid, which induced an acidic medium that directly reduced the outbreak of pathogens and aerobic spoilage microorganisms (Sayin and Alkan, 2015). Sugar was considered an effective substrate of pickling production (Ozer and Yildirim, 2019). Sugar was supplemented as an ideal preservative to speed up fermentation velocity and contribute sweet taste of the pickle (Misha, 2019). Firmness and acidity are directly related to the organoleptic properties of the pickle and consumer acceptance. *Lb. plantarum* was proven to tolerate effectively in high sugar content (Nout, 1994). Vegetable pickles fermented in 8% sodium chloride + 1% sugar resulted in the highest sensory score (Sultana *et al*., 2014). Sugar (2%) was adequate for the pickling of cabbage at 25-28°C for 30-40 days (Ozer and Yildirim, 2019). Appropriate incorporation of sugar effectively minimized the proliferation of food-borne microorganisms (Misha, 2019).

3.5 Effect of fermentation time on physicochemical, phytochemical and sensory characteristics of pickled water hyacinth stem

It's easily noticed that the positive influence of pickling time (2-6 days) to total phenolic content (58.24±0.00 to 61.07±0.04 mg GAE/ 100 g), total antioxidant capacity (7.32±0.03 to 7.79±0.02 mg AAE/g) and overall acceptance (8.67±0.01 to 8.91±0.03) of pickled young water hyacinth stem. There was a degradable trend of total phenolic content, total antioxidant capacity and sensory characteristics of pickle from 6 to 10 days of fermentation. Firmness gradually reduced (12.09±0.01 down to 10.15±0.03 N) while acidity increased (1.27±0.02 to 1.78±0.04 %) from 2-10 days (Table 5). The pickling process for young water hyacinth stems should be stopped at the 6^{th} day to maintain the best quality attributes. Sweet potato was pickled in a brine solution (2–10%) with an inoculum of *Lb. plantarum* culture for 4 weeks (Panda *et al*., 2009). Elephant foot yam was fermented by *Lb. plantarum* (10%, v/v) in 8% (w/v) brine solution for 22 days (Behera *et al*., 2018). Extension of fermentation duration with *Lactobacillus plantarum* produced much more short -chain fatty acids in sweet potato pickle. Total acidity accumulated to 0.56±0.02% at the final of pickling at 24

Table 4. Effect of sugar ratio supplementation (2-4%) on physicochemical, phytochemical and sensory characteristics of pickled young water hyacinth stem.

Variables	Sugar ratio (%) supplementation				
	2	2.5	3.0	3.5	4.0
Firmness (N)	11.24±0.00^{bc}	11.76±0.03^{ab}	12.09±0.01^{a}	11.50±0.00^{b}	10.87±0.01^{c}
Acidity (%)	0.98±0.01^{bc}	1.18±0.01^{ab}	1.27±0.02^{a}	1.05±0.03^{b}	0.82±0.00^{c}
TPC (mg GAE/100 g)	51.97±0.04^{bc}	55.47±0.00^{ab}	58.24±0.00^{a}	53.28±0.01^{b}	49.74±0.03^{c}
TAC (mg AAE /g)	6.23±0.02^{bc}	6.91±0.04^{ab}	7.32±0.03^{a}	6.60±0.00^{b}	5.95±0.02^{c}
Overall acceptance	8.02±0.00^{bc}	8.50±0.03^{ab}	8.67±0.01^{a}	8.37±0.02^{b}	7.69±0.00^{c}

Values are presented as mean±SD of three replicates. Values with different superscripts in the same row are statistically significantly different ($\alpha = 0.05$).

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Table 5. Effect of fermentation time on physicochemical, phytochemical and sensory characteristics of pickled young water hyacinth stem.

Variables	Fermentation time (days)				
	2	4	6	8	10
Firmness (N)	12.09±0.01^{a}	12.03±0.04^{a}	11.86±0.03^{ab}	11.64±0.00^{b}	10.15±0.03^{c}
Acidity (%)	1.27±0.02^{c}	1.34±0.00^{bc}	1.50±0.01^{b}	1.61±0.01^{ab}	1.78±0.04^{a}
TPC (mg GAE/100 g)	58.24±0.00^{b}	59.36±0.01^{ab}	61.07±0.04^{a}	53.76±0.04^{bc}	50.14±0.00^{c}
TAC (mg AAE /g)	7.32±0.03^{b}	7.44±0.03^{ab}	7.79±0.02^{a}	7.01±0.02^{bc}	6.57±0.03^{c}
Overall acceptance	8.67±0.01^{b}	8.72±0.02^{ab}	8.91±0.03^{a}	8.24±0.01^{bc}	8.00±0.02^{c}

Values are presented as mean±SD of three replicates. Values with different superscripts in the same row are statistically significantly different ($\alpha = 0.05$).

hours (Insani and Wikandari, 2024). As the fermentation duration extended, the strain growth and proliferation were improved, and the acidity accumulation rate was promoted, causing a faster pH reduction. Hence, pickling duration considerably enhanced the aroma property and abundance of metabolites in the pickle (Yanan *et al*., 2025). Fermentation time directly influenced the rigidity of texture firmness and function of prebiotics and probiotics (Ahmada *et al*., 2025).

4. Conclusion

Water hyacinth (*Eichhornia crassipes* Solms) is an underutilized vegetable. This research revealed the efficiency of calcium ions to improve the texture firmness and overall acceptance of pickled young water hyacinth stems. *Lactiplantibacillus plantarum* was able to endure acidic conditions to grow, proliferate and biosynthesize metabolites contributing to high overall acceptance of pickle. Natural young water hyacinth could be converted into a healthy pickle food for daily consumption.

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