

# Quantitative analysis of biogenic amine production of different lactic acid bacteria isolated from ready-to-eat packaged fish products

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## Abstract

The ability of lactic acid bacteria (LAB) to produce biogenic amines (BAs) from amino acids using amino acid decarboxylase enzymes is an important food safety criterion due to their use as starter or bio-protective cultures. In this study, various LAB isolates, including *Lactococcus* (three isolates), *Lactobacillus* (five isolates), *Enterococcus* (13 isolates), and *Leuconostoc* (seven isolates), were isolated from ready-to-eat fish products like sauced, marinated, smoked anchovies, and smoked mackerel. These isolates were then tested for their ability to produce BAs (histamine, putrescine, cadaverine, spermidine, tryptamine, 2-phenylethylamine, spermine, serotonin, tyramine, 3-methylamine, and dopamine) and ammonia in histidine decarboxylase broth. The post-biotic solutions (cell-free supernatant) of *Lb. paracasei* NZ.Lbp.111, *Lb. brevis* NZ.Lbb.085, and *E. casseliflavus* NZ.Ec.074 exhibited the highest ammonia levels. Histamine accumulation was generally low in post-biotic solutions from four LAB isolates, ranging from 2.00 to 7.78 ppm. However, the post-biotic solution of *Leu. mesenteroides* NZLeu 009 displayed a significantly higher histamine concentration (83.23 ppm). *Lactobacillus* post-biotic solutions had the highest concentrations of ammonia (1220.28 ppm), 2-phenylethylamine (82.96 ppm), serotonin (278.70 ppm), tyramine (267.48 ppm), and cadaverine (19.72 ppm). Also, the average BAs concentration for *Lactobacillus* post-biotic solutions was the highest at 31.98 ppm. The results revealed the analysis of BAs concentrations in different LAB isolates from fish products, providing interesting insights into their metabolic capabilities and potential implications for food safety and quality.

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## Introduction

Different types of biogenic amines (BAs) can be classified based on their chemical structure. These include aliphatic BAs, such as putrescine (PUT), cadaverine (CAD), spermine (SPM), and spermidine (SPD), aromatic BAs, such as tyramine (TYR) and 2-phenylethylamine (PHE), and heterocyclic BAs, such as histamine (HIS) and tryptamine (TPT).<sup>1,2</sup> Overall, this information highlights the intricate balance between the role of BAs as immune mediators and neurotransmitters, and their vital contributions to the fundamental cellular processes. They play a significant role in various physiological functions of eukaryotic cells, including the synthesis of hormones, alkaloids, and other bioactive components.<sup>3</sup>

The BAs pose a risk to human health when present in foods above the recommended limits.<sup>4</sup> The health effects of BAs depend on factors, such as the type of amine,

individual sensitivity, and the presence of allergies.<sup>5</sup> Consuming monoamine oxidase inhibitor drugs or ethanol increases the risk of interference with amino oxidase enzymatic systems, being responsible for exogenous Bas detoxification.<sup>5</sup> Elevated levels of BAs in food are associated with food safety concerns and potential health complications for consumers.<sup>6-8</sup>

Lactic acid bacteria (LAB) are recognized as potent reducers of BAs in fermented foods, making them a subject of extensive research.<sup>9-11</sup> Beyond their well-established role in fermented food production, LAB exhibit a diverse array of beneficial properties, including lactic acid production, lactose reduction, and improvement in the sensory, physical, and chemical characteristics of food. Also, LAB have been shown to effectively control food-borne pathogens.<sup>4,9,12</sup> However, LAB can also possess microbial decarboxylases responsible for BAs formation, similar to food-spoilage pathogenic microorganisms.<sup>6</sup> The

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LAB can produce BAs through the decarboxylase enzymes action, which remove carboxyl groups from specific amino acids. These BA-producing LAB can be naturally present in the food microbiota or deliberately introduced as a starter or co-culture. While published documents highlight the ubiquitous presence of BAs in fermented foods, their concentrations can vary considerably.<sup>1</sup> Examples include beverages, fermented vegetables, and soy products typically containing 20.00 mg kg<sup>-1</sup> of BAs, while certain sausages and cheeses may reach levels of 100 mg kg<sup>-1</sup>.<sup>13</sup>

Understanding the BA-producing abilities of LAB genera isolated from fish products is crucial for assessing their impact on both product quality and consumer health. This study aimed to determine the concentration of BAs produced by LAB in fish-derived fermented products. Additionally, it provides a broader perspective on the interplay between LAB, BAs, and the safety and quality of fermented fish products in the food industry.

## Materials and Methods

**The LAB isolation and characterization.** In this study, 29 samples (ready-to-eat, sauce-smoked marine fish) were collected from three different food sources. After homogenizing the food samples (10.00 g sample per 90.00 mL Ringer solution *per* sample), 10<sup>5</sup> and 10<sup>6</sup> dilutions were prepared. The double-layer sandwich method was used with de Man, Rogosa and Sharpe (MRS; Merck, Darmstadt, Germany) and M-17 broths (Merck). Subsequently, 128 LAB isolates were characterized from 1,000 isolates obtained from food samples using phenotypic morphology, molecular, and biochemical tests.<sup>14</sup> From these 128 species, 28 isolates were selected for the present study (Table 1).

**Post-biotic solution from LAB isolates.** The LAB isolates were pre-incubated in MRS broth at 37.00 °C

for 18 hr before their ability to produce BAs in histidine decarboxylase broth (HDB). After obtaining fresh cultures of each LAB isolate, 1.00% inoculation volume was added to the HDB to form BAs. The BAs formation in the post-biotic solution of LAB isolates was conducted in HDB containing 1.00 g Lab-Lemco powder (Oxoid, Basingstoke, UK), 5.00 g NaCl (Merck), 8.02 g L-HIS (Sigma, Steinheim, Germany), and 5.00 mg pyridoxal HCl (Sigma) in 1,000 mL of distilled water.<sup>15</sup> To adjust pH, 1.00 M KOH (Riedel-de Haen, Seelze, Germany) or 6.00% (v per v) trichloroacetic acid (Riedel-de Haen) was used. Subsequently, selected previously sub-cultured LAB isolates were inoculated into sterilized HDB and incubated for 72 hr at 37.00 °C under anaerobic conditions. Consequently, a post-biotic solution from the supernatant (4.00 mL) of each bacterial culture was extracted for further analysis to determine the BA.

**Ammonia (AMN) and BAs quantification.** Prior to reversed-phase high-performance liquid chromatography (RP-HPLC) analysis, BAs in the post-biotic solution were derivatized following the procedure described by Toy *et al.*<sup>16</sup> The analysis of 10 BAs and AMN was performed using RP-HPLC. The high-performance liquid chromatography (HPLC) analyses were made using a Shimadzu Prominence HPLC apparatus (Shimadzu, Kyoto, Japan) which consisted of the apparatus with SPD-M20A diode array detector, column oven, and associated components. Separation and quantification were carried out using a Phenomenex ODS Hypersil column (5.00 µm × 250 × 4.60 mm) following a rapid elution program.<sup>16</sup> Ammonia separation was carried out using the same injection of BA determination.<sup>9</sup>

**Statistical analysis.** One-way analysis of variance using SPSS Software (version 17.0; IBM Corp., Armonk, USA) was utilized for analysis of BAs production by LAB. The level of significance was set at  $p < 0.05$ , and means were compared using Duncan's *t*-test.

**Table 1.** Lactic acid bacteria (LAB) strains isolated from ready-to-eat fish products, such as *Lactobacilli*, *Enterococci*, *Leuconostoc*, and *Lactococcus* and their strain codes.

LAB genus	Strains	Strain codes
<b><i>Pediococcus</i></b>	<i>Pediococc</i>	NZ.Pa.026
<b><i>Lactobacilli</i></b>	<i>Lactobacillus rhamnosus</i>	NZ.Lbr.082,
	<i>Lactobacillus paracasei</i>	NZ.Lbp.105, NZ.Lbp.111
	<i>Lactobacillus casei</i>	NZ.Lbc.117
	<i>Lactobacillus brevis</i>	NZ.Lbb.085
	<i>Lactobacillus Sakei</i>	ATCC 15
<b><i>Enterococci</i></b>	<i>Enterococcus hirae</i>	NZ.Eh.035
	<i>Enterococcus faecalis</i>	NZ.Ef.040, NZ.Ef.042, NZ.Ef.044
	<i>Enterococcus lactis</i>	NZ.El.049, NZ.El.052
	<i>Enterococcus faecium</i>	NZ.Efc.056
	<i>Enterococcus durans</i>	NZ.Ed.069, NZ.Ed.070
	<i>Enterococcus casseliflavus</i>	NZ.Ec.074
<b><i>Lactococci</i></b>	<i>Lactococcus lactis subs. lactis</i>	NZ.Lcl.011, NZ.Lcc.023, NZ.Lcl.018
	<i>Pediococcus acidophilus</i>	NZ.Pa.026
	<i>Pediococcus acidophilus</i>	ATCC 25741
<b><i>Leuconostoc</i></b>	<i>Leuconostoc mesenteroides subs. mesenteroides</i>	NZLeu.002, NZLeu.003, NZLeu.004, , NZLeu.006, NZLeu.007, NZLeu.008, NZLeu.009

**Results**

The ability of LAB, including *Enterococcus* (10 isolates), *Leuconostoc* (seven isolates), *Lactococcus* (three isolates), and *Lactobacillus* (six isolates), to accumulate BAs in HDB was investigated. A post-biotic solution was used to measure AMN and BAs formation by *Lactobacillus* spp. and the reference strain *Lactobacillus sakei* ATCC 1522 (Table 2). The mean values and standard deviations indicated variability within each strain type. These isolates exhibited significant variability in AMN production. The *Lactobacillus paracasei* NZ.Lbp.111 exhibited the highest concentrations of AMN, HIS, and PUT in post-biotic solution. The post-biotic solution from *Lb. paracasei* NZLbp.111 and *Lactobacillus brevis* NZLbb.085 produced AMN at concentrations of 2788.98 ppm and 1582.54 ppm, respectively. The *Lb. brevis* NZ.Lbb.085 had the highest AMN concentration, indicating its strong ability to produce AMN. The post-biotic solution from *Lb. sakei* ATCC 1522 had the lowest AMN concentration among all isolates tested. The HIS concentrations were relatively low in the post-biotic solutions for all isolates. The post-biotic solution from *Lb. brevis* NZ.Lbr.082 had the highest HIS concentrations, although the levels were generally moderate. The results showed that the concentration of HIS in the post-biotics from all *Lactococci* was between 2.00 and 0.84 ppm. In contrast, post-biotic solutions from the *Lactobacillus* isolates were found to be capable of accumulating higher levels of BAs, such as PUT, CAD, SPD, TPT, PHE, SPM, 3-methylamine (TMA), dopamine (DOP), and agmatine (AGM).

The *Lb. paracasei* Lbp.105 produced remarkably high levels of serotonin (SER) and TYR, exceeding 1000 ppm, despite low AMN production. Other isolates such as *Lb. paracasei* NZ.Lbp.111, *Lb. brevis* NZ.Lbr.082, and *Lactobacillus casei* NZ.Lbc.117 also showed moderate to high levels of various BAs. The *Lb. brevis* NZLbb.085 consistently displayed the lowest BAs concentrations, while the reference strain *Lb. sakei* ATCC 1522 accumulated moderate levels of SER and PUT (Table 2). These findings highlighted the diverse BA-production potential of *Lactobacillus* isolates, being crucial for understanding their safety as food additives.

Ten *Enterococcus* isolates were investigated for their ability to produce AMN and BAs (HIS, PUT, CAD, SPD, TPT, PHE, SPM, TYR, and AGM) in a post-biotic solution (Table 3). While all isolates accumulated less BA than AMN, *Enterococcus casseliflavus* NZ.Ec.074 displayed the highest AMN concentration (1,302.95 ppm) compared to others (180-590 ppm). All isolates exhibited low HD activity, leading to minimal HIS accumulation (0.13 - 7.78 ppm). Similarly, except for NZ.Ec.074 (the highest at 69.99 ppm), other isolates showed low PUT production (8.28 - 0.13 ppm).

**Table 2.** Biogenic amines (ppm) forming ability of *Lactobacillus* strains isolated from ready-to-eat fish in enriched L-histidine aminoacide medium. Mean values and standard deviations were determined from four observations (n = 4).

Strains	AMN	HIS	PUT	CAD	SPD	TPT	PHE	SPM	SER	TYR	TMA	DOP	AGM
<b>NZ.Lbb.085</b>	1,582.54 ± 39.00 <sup>b</sup>	0.84 ± 0.25 <sup>d</sup>	0.25 ± 0.25 <sup>e</sup>	12.58 ± 0.25 <sup>d</sup>	2.14 ± 0.25 <sup>d</sup>	1.49 ± 0.25 <sup>a</sup>	34.13 ± 0.75 <sup>c</sup>	15.35 ± 0.25 <sup>d</sup>	2.57 ± 0.25 <sup>b</sup>	1.99 ± 0.25 <sup>b</sup>	0.28 ± 0.25 <sup>c</sup>	1.08 ± 0.25 <sup>d</sup>	1.15 ± 0.25 <sup>d</sup>
<b>NZ.Lbc.117</b>	457.48 ± 25.20 <sup>d</sup>	2.00 ± 0.50 <sup>a</sup>	4.06 ± 0.50 <sup>bc</sup>	18.20 ± 0.50 <sup>c</sup>	1.95 ± 0.50 <sup>e</sup>	3.22 ± 0.50 <sup>a</sup>	79.98 ± 1.00 <sup>a</sup>	42.72 ± 0.50 <sup>a</sup>	6.13 ± 0.50 <sup>b</sup>	10.95 ± 0.50 <sup>c</sup>	0.50 ± 0.50 <sup>c</sup>	0.50 ± 0.50 <sup>d</sup>	77.98 ± 0.50 <sup>a</sup>
<b>NZ.Lbr.082</b>	779.36 ± 8.95 <sup>c</sup>	1.57 ± 0.20 <sup>b</sup>	94.62 ± 1.00 <sup>a</sup>	6.93 ± 0.20 <sup>d</sup>	23.06 ± 0.20 <sup>b</sup>	3.67 ± 0.20 <sup>a</sup>	9.65 ± 0.20 <sup>e</sup>	1.49 ± 0.20 <sup>e</sup>	1.16 ± 0.20 <sup>b</sup>	6.10 ± 0.20 <sup>c</sup>	1.73 ± 0.20 <sup>c</sup>	0.20 ± 0.20 <sup>cd</sup>	54.85 ± 3.13 <sup>b</sup>
<b>NZ.Lbp.111</b>	2,788.98 ± 88.50 <sup>a</sup>	1.55 ± 1.00 <sup>b</sup>	5.90 ± 1.00 <sup>b</sup>	7.38 ± 1.00 <sup>e</sup>	1.00 ± 1.00 <sup>e</sup>	3.44 ± 1.00 <sup>a</sup>	24.91 ± 1.38 <sup>d</sup>	10.07 ± 1.00 <sup>d</sup>	3.99 ± 1.00 <sup>b</sup>	5.03 ± 1.00 <sup>c</sup>	1.21 ± 1.00 <sup>c</sup>	87.06 ± 2.38 <sup>b</sup>	13.92 ± 1.00 <sup>c</sup>
<b>NZ.Lbp.105</b>	493.06 ± 11.79 <sup>d</sup>	1.19 ± 0.20 <sup>c</sup>	2.33 ± 2.33 <sup>d</sup>	53.54 ± 4.04 <sup>a</sup>	35.81 ± 3.33 <sup>a</sup>	4.22 ± 2.61 <sup>a</sup>	55.42 ± 4.13 <sup>b</sup>	29.11 ± 1.53 <sup>b</sup>	1379.64 ± 47.77 <sup>a</sup>	1313.34 ± 17.26 <sup>a</sup>	122.30 ± 24.00 <sup>a</sup>	32.93 ± 4.27 <sup>c</sup>	11.99 ± 2.04 <sup>c</sup>
<b>Lb. sakei ATCC 15</b>	488.16 ± 7.50 <sup>d</sup>	0.86 ± 0.00 <sup>d</sup>	2.86 ± 0.06 <sup>d</sup>	26.89 ± 0.38 <sup>b</sup>	16.03 ± 0.63 <sup>c</sup>	0.00 ± 0.00 <sup>e</sup>	50.85 ± 0.07 <sup>b</sup>	22.60 ± 0.05 <sup>c</sup>	13.31 ± 0.13 <sup>b</sup>	162.85 ± 0.01 <sup>b</sup>	8.60 ± 0.05 <sup>b</sup>	116.40 ± 0.25 <sup>a</sup>	14.66 ± 2.05 <sup>c</sup>

AMN: Ammonia; HIS: Histamine; PUT: Putrescine; CAD: Cadaverine; SPD: Spermidine; TPT: Tyryptamine; PHE: 2-phenylethylamine; SPM: Spermine; SER: Serotonin; TYR: Tyramine; TMA: 3-methylamine; DOP: Dopamine; and AGM: Agmatine.  
<sup>a-d</sup> Values in the same column followed by the same superscript letters are not significantly different (*p* > 0.05).

The highest CAD production was observed in NZ.El.052 and *Enterococcus durans* NZ.Ed.069 (13.00 – 10.00 ppm). Accumulation of other amines (SPD, TPT, PHE, SPM, TYR, and AGM) ranged from 32.93 to 102.72 ppm. Notably, BA production in most *Enterococcus* species was below 10 ppm. Four isolates (NZ.El.049, NZ.El.052, NZ.Efc.056, and NZ.Ec.074) displayed the highest SPD concentration (17.59 - 39.92 ppm). Additional accumulations were observed for PHE (102.02 ppm), SER (40.52 ppm), TYR (70.48 ppm), TMA (101.59 ppm), DOP (256.03 ppm), and AGM (27.77 ppm). *Enterococcus* isolates exhibited significant variability in BAs production, with NZ.Ec.074 consistently demonstrating higher levels of various amines.

Seven *Leuconostoc* isolates were investigated for their ability to accumulate BAs in post-biotic solutions (Table 4). *Leuconostoc* isolates generally exhibited a lower ability to produce BAs compared to AMN. The AMN accumulation ranged from 200 to 530 ppm, with the exception of *Leuconostoc mesenteroides* subsp. *mesenteroides* NZ.Leu.009, which showed the lowest value at 3.74 ppm. The HIS concentration in most *Leuconostoc* post-biotic solutions was very low (1.95 and 0.38 ppm), indicating a lack of HDenzyme activity. However, isolate *Leu. mesenteroides* subsp. *mesenteroides* NZLeu.009 displayed a significantly higher HIS concentration of 83.69 ppm. The PUT accumulation was observed in all *Leuconostoc* isolates, except NZLeu.009, ranging from 5.11 to 0.25 ppm. Additionally, *Leu. mesenteroides* subsp. *mesenteroides* NZLeu.008 showcased the highest CAD accumulation (13.32 ppm) among the isolates. Finally, the highest DOP and AGM accumulations were observed in

*Leu. mesenteroides* subsp. *mesenteroides* NZLeu.003 (79.43 ppm) and NZLeu.006 (68.50 ppm), respectively. Overall, *Leuconostoc* isolates exhibited significant variability in BAs production.

The production of BAs by *Lactococcus* isolates and the reference strain *Pediococcus acidophilus* in HDB is presented in Table 5. The *P. acidophilus* displayed the highest AMN accumulation (1764.15 ppm), highlighting its substantial capacity for AMN production. Conversely, *Lactococcus lactis* subsp. *lactis* NZ.Lcl.011 exhibited the lowest AMN concentration (886.20 ppm). Notably, *Lactococcus* isolates accumulated approximately four times more AMN than other genera. Histamine levels, which are crucial for food safety assessments, remained relatively low across all isolates. The lowest HIS accumulation (0.95 ppm) was observed in NZ.Lcl.018, while NZ.Lcc.023 displayed the highest (2.46 ppm). Interestingly, *P. acidophilus* exhibited higher HIS accumulation (7.63 ppm) compared to all *Lactococcus* isolates. This variability suggests differences in metabolic pathways and growth conditions. While low HIS levels are desirable in food production, *Lactococcus* isolates demonstrated a significant capacity for specific amines, such as SER and TYR. The NZ.Lcl.011 and NZ.Lcl.018 reached the highest SER and TYR concentrations (30.38 ppm and 41.45 ppm, respectively), indicating substantial BAs production. The *L. lactis* subsp. *lactis* NZ.Lcl.011 showcased the highest PHE concentration (248.63 ppm), while NZ.Lcl.018 displayed higher SER concentration (9.18 ppm) than NZ.Lcc.023 (5.32 ppm), which had the lowest concentration. Similarly, NZ.Lcl.018 had lower SPD (4.63 ppm) and TPT (1.55 ppm);

**Table 3.** Biogenic amines (ppm) forming ability of *Enterococcus* strains isolated from ready-to-eat fish in enriched L-histidine aminoacide medium. Mean values and standard deviations were determined from four observations (n = 4).

Strains	AMN	HIS	PUT	CAD	SPD	TPT	PHE	SPM	SER	TYR	TMA	DOP	AGM
<b>NZ.Eh.035</b>	306.25 ± 12.88 <sup>d</sup>	0.81 ± 0.01 <sup>c</sup>	3.30 ± 0.01 <sup>c</sup>	1.71 ± 0.01 <sup>e</sup>	1.51 ± 0.01 <sup>d</sup>	1.09 ± 0.01 <sup>e</sup>	42.01 ± 1.13 <sup>e</sup>	17.43 ± 0.01 <sup>e</sup>	5.40 ± 0.01 <sup>c</sup>	6.75 ± 0.01 <sup>e</sup>	0.36 ± 0.01 <sup>b</sup>	20.11 ± 0.25 <sup>c</sup>	8.75 ± 0.25 <sup>e</sup>
<b>NZ.El.049</b>	334.28 ± 92.50 <sup>c</sup>	0.52 ± 0.12 <sup>cd</sup>	0.13 ± 0.00 <sup>d</sup>	0.13 ± 0.00 <sup>f</sup>	17.59 ± 0.13 <sup>b</sup>	0.63 ± 0.03 <sup>e</sup>	33.92 ± 0.63 <sup>f</sup>	14.75 ± 0.13 <sup>f</sup>	3.15 ± 0.13 <sup>d</sup>	9.07 ± 0.13 <sup>d</sup>	0.19 ± 0.00 <sup>b</sup>	2.67 ± 0.13 <sup>e</sup>	5.18 ± 0.13 <sup>f</sup>
<b>NZ.El.052</b>	595.34 ± 0.88 <sup>b</sup>	1.99 ± 0.00 <sup>b</sup>	3.22 ± 0.88 <sup>c</sup>	13.02 ± 0.88 <sup>a</sup>	18.52 ± 0.88 <sup>b</sup>	6.23 ± 0.88 <sup>c</sup>	102.07 ± 1.13 <sup>a</sup>	66.38 ± 0.88 <sup>b</sup>	2.39 ± 0.88 <sup>d</sup>	13.92 ± 0.88 <sup>b</sup>	0.97 ± 0.01 <sup>b</sup>	8.47 ± 0.88 <sup>d</sup>	7.59 ± 0.88 <sup>e</sup>
<b>NZ.Ed.069</b>	228.51 ± 25.31 <sup>e</sup>	1.57 ± 0.01 <sup>b</sup>	4.66 ± 0.31 <sup>c</sup>	10.48 ± 0.31 <sup>b</sup>	5.78 ± 0.31 <sup>c</sup>	0.31 ± 0.00 <sup>e</sup>	72.12 ± 0.31 <sup>b</sup>	36.94 ± 1.88 <sup>c</sup>	3.75 ± 0.31 <sup>c</sup>	9.83 ± 0.31 <sup>c</sup>	0.43 ± 0.00 <sup>b</sup>	0.31 ± 0.00 <sup>e</sup>	21.69 ± 1.50 <sup>c</sup>
<b>NZ.Efc.056</b>	304.56 ± 11.63 <sup>d</sup>	1.88 ± 0.00 <sup>b</sup>	8.28 ± 0.38 <sup>b</sup>	6.44 ± 0.01 <sup>d</sup>	39.92 ± 0.01 <sup>a</sup>	12.82 ± 1.12 <sup>a</sup>	67.58 ± 4.38 <sup>c</sup>	24.40 ± 1.38 <sup>d</sup>	13.00 ± 0.78 <sup>b</sup>	4.17 ± 0.05 <sup>g</sup>	0.43 ± 0.00 <sup>b</sup>	0.38 ± 0.01 <sup>e</sup>	32.93 ± 2.25 <sup>a</sup>
<b>NZ.Ed.070</b>	184.85 ± 6.47 <sup>f</sup>	0.23 ± 0.01 <sup>cd</sup>	0.23 ± 0.01 <sup>d</sup>	0.23 ± 0.00 <sup>e</sup>	0.23 ± 0.00 <sup>d</sup>	0.23 ± 0.01 <sup>e</sup>	12.50 ± 0.23 <sup>g</sup>	4.87 ± 0.23 <sup>h</sup>	0.23 ± 0.00 <sup>d</sup>	1.25 ± 0.22 <sup>h</sup>	0.23 ± 0.00 <sup>b</sup>	0.23 ± 0.00 <sup>e</sup>	0.87 ± 0.03 <sup>g</sup>
<b>NZ.Ef.040</b>	187.50 ± 9.12 <sup>f</sup>	0.38 ± 0.01 <sup>cd</sup>	0.38 ± 0.01 <sup>d</sup>	0.38 ± 0.02 <sup>f</sup>	0.38 ± 0.01 <sup>d</sup>	0.38 ± 0.02 <sup>e</sup>	12.65 ± 0.38 <sup>g</sup>	5.02 ± 0.38 <sup>h</sup>	0.38 ± 0.01 <sup>d</sup>	1.40 ± 0.00 <sup>h</sup>	0.38 ± 0.01 <sup>b</sup>	0.38 ± 0.00 <sup>e</sup>	1.02 ± 0.02 <sup>g</sup>
<b>NZ.Ef.044</b>	208.32 ± 10.13 <sup>e</sup>	0.13 ± 0.03 <sup>d</sup>	0.13 ± 0.01 <sup>d</sup>	0.13 ± 0.01 <sup>f</sup>	8.09 ± 1.63 <sup>c</sup>	0.43 ± 0.03 <sup>e</sup>	6.19 ± 0.13 <sup>h</sup>	1.34 ± 0.13 <sup>i</sup>	0.13 ± 0.01 <sup>d</sup>	5.65 ± 0.13 <sup>f</sup>	0.28 ± 0.00 <sup>b</sup>	3.09 ± 0.13 <sup>e</sup>	1.91 ± 0.13 <sup>g</sup>
<b>NZ.Ec.074</b>	1,302.95 ± 12.69 <sup>a</sup>	7.78 ± 0.19 <sup>a</sup>	69.99 ± 2.75 <sup>a</sup>	7.63 ± 0.19 <sup>c</sup>	39.28 ± 5.25 <sup>a</sup>	7.34 ± 0.19 <sup>b</sup>	65.10 ± 2.88 <sup>d</sup>	71.75 ± 1.75 <sup>a</sup>	40.52 ± 7.00 <sup>a</sup>	70.48 ± 0.19 <sup>a</sup>	101.59 ± 10.63 <sup>a</sup>	256.03 ± 8.75 <sup>a</sup>	27.77 ± 1.63 <sup>b</sup>
<b>NZ.Ef.042</b>	273.97 ± 25.13 <sup>d</sup>	0.13 ± 0.13 <sup>d</sup>	0.13 ± 0.03 <sup>d</sup>	0.13 ± 0.01 <sup>f</sup>	4.98 ± 0.13 <sup>c</sup>	0.13 ± 0.00 <sup>e</sup>	12.64 ± 0.13 <sup>g</sup>	7.11 ± 0.13 <sup>g</sup>	16.57 ± 0.13 <sup>b</sup>	6.26 ± 0.13 <sup>e</sup>	0.18 ± 0.00 <sup>b</sup>	41.40 ± 2.00 <sup>b</sup>	11.06 ± 0.13 <sup>d</sup>

AMN: Ammonia; HIS: Histamine; PUT: Putrescine; CAD: Cadaverine; SPD: Spermidine; TPT: Tyriptamine; PHE: 2-phenyletilamine; SPM: Spermine; SER: Serotonin; TYR: Tyramine; TMA: 3-methylamine; DOP: Dopamine; and AGM: Agmatine.

<sup>a-d</sup> Values in the same column followed by the same superscript letters are not significantly different ( $p > 0.05$ ).

**Table 4.** Biogenic amines (ppm) forming ability of *Leuconostoc* strains isolated from ready-to-eat fish in enriched L-histidine aminoacide medium. Mean values and standard deviations were determined from four observations (n = 4).

Strains	AMN	HIS	PUT	CAD	SPD	TPT	PHE	SPM	SER	TYR	TMA	DOP	AGM
NZLeu.002	384.92 ± 7.69 <sup>b</sup>	0.65 ± 0.49 <sup>c</sup>	1.17 ± 1.81 <sup>cd</sup>	0.69 ± 0.99 <sup>c</sup>	11.90 ± 0.40 <sup>b</sup>	4.07 ± 0.062 <sup>b</sup>	20.16 ± 1.52 <sup>e</sup>	10.28 ± 0.89 <sup>d</sup>	36.34 ± 25.31 <sup>d</sup>	15.36 ± 1.02 <sup>f</sup>	40.1 ± 2.51 <sup>c</sup>	12.45 ± 0.63 <sup>d</sup>	6.49 ± 0.98 <sup>e</sup>
	NZLeu.007	376.35 ± 7.63 <sup>b</sup>	0.38 ± 0.13 <sup>c</sup>	0.13 ± 0.13 <sup>d</sup>	0.13 ± 0.13 <sup>c</sup>	0.13 ± 0.13 <sup>d</sup>	0.13 <sup>a</sup>	29.66 ± 1.50 <sup>d</sup>	11.95 ± 0.13 <sup>d</sup>	50.95 ± 0.13 <sup>c</sup>	21.15 ± 0.13 <sup>e</sup>	60.02 ± 0.13 <sup>b</sup>	18.01 ± 0.13 <sup>cd</sup>
NZLeu.006		532.16 ± 12.75 <sup>a</sup>	1.29 ± 0.25 <sup>bc</sup>	5.11 ± 0.25 <sup>c</sup>	1.62 ± 0.25 <sup>b</sup>	2.62 ± 0.25 <sup>c</sup>	1.44 ± 0.25 <sup>c</sup>	80.94 ± 3.13 <sup>c</sup>	35.49 ± 1.00 <sup>b</sup>	1.28 ± 0.25 <sup>f</sup>	11.84 ± 0.25 <sup>g</sup>	0.25 ± 0.25 <sup>e</sup>	0.25 ± 0.25 <sup>f</sup>
	NZLeu.003	213.16 ± 3.50 <sup>e</sup>	1.95 ± 0.25 <sup>bc</sup>	0.25 ± 0.25 <sup>d</sup>	2.11 ± 0.25 <sup>c</sup>	12.2 ± 0.25 <sup>b</sup>	0.25 ± 0.05 <sup>d</sup>	97.52 ± 0.25 <sup>b</sup>	54.76 ± 0.25 <sup>a</sup>	61.75 ± 0.75 <sup>b</sup>	28.85 ± 0.50 <sup>d</sup>	1.96 ± 0.62 <sup>e</sup>	79.43 ± 1.13 <sup>a</sup>
NZLeu.004		244.50 ± 6.25 <sup>d</sup>	1.76 ± 0.01 <sup>bc</sup>	1.87 ± 0.03 <sup>d</sup>	2.56 ± 0.00 <sup>b</sup>	10.12 ± 0.00 <sup>b</sup>	5.37 ± 0.05 <sup>a</sup>	166.86 ± 5.19 <sup>a</sup>	55.23 ± 1.25 <sup>a</sup>	0.95 ± 0.00 <sup>f</sup>	39.96 ± 2.50 <sup>b</sup>	0.04 ± 0.00 <sup>e</sup>	20.02 ± 0.00 <sup>c</sup>
	NZLeu.008	271.32 ± 6.50 <sup>c</sup>	1.08 ± 0.25 <sup>bc</sup>	4.00 ± 0.25 <sup>b</sup>	13.32 ± 0.25 <sup>a</sup>	2.78 ± 0.25 <sup>c</sup>	0.25 ± 0.00 <sup>d</sup>	15.85 ± 0.24 <sup>f</sup>	13.24 ± 1.13 <sup>c</sup>	9.41 ± 1.38 <sup>e</sup>	53.03 ± 2.75 <sup>a</sup>	5.34 ± 1.50 <sup>d</sup>	29.06 ± 0.25 <sup>b</sup>
NZLeu.009		3.74 ± 0.25 <sup>f</sup>	83.69 ± 1.87 <sup>a</sup>	213.78 ± 12.75 <sup>a</sup>	0.25 ± 0.25 <sup>c</sup>	462.93 ± 5.63 <sup>a</sup>	0.25 ± 0.00 <sup>d</sup>	96.35 ± 2.87 <sup>b</sup>	58.36 ± 1.38 <sup>a</sup>	284.17 ± 0.25 <sup>a</sup>	35.13 ± 1.63 <sup>c</sup>	247.88 ± 2.75 <sup>a</sup>	2.15 ± 1.13 <sup>e</sup>

AMN: Ammonia; HIS: Histamine; PUT: Putrescine; CAD: Cadaverine; SPD: Spermidine; TPT: Tyriptamine; PHE: 2-phenyletilamine; SPM: Spermine; SER: Seretonin; TYR: Tyramine; TMA: 3-methylamine; DOP: Dopamine; and AGM: Agmatine.

<sup>a-f</sup> Values in the same column followed by the same superscript letters are not significantly different ( $p > 0.05$ ).

**Table 5.** Biogenic amines (ppm) forming ability of *Lactococcus* strains isolated from ready-to-eat fish in enriched L-histidine aminoacide medium. Mean values and standard deviations were determined from four observations (n = 4).

Strains	AMN	HIS	PUT	CAD	SPD	TPT	PHE	SPM	SER	TYR	TMA	DOP	AGM
NZ.Lcl.011	886.20 ± 7.42 <sup>c</sup>	± 1.46 ± 0.35 <sup>c</sup>	± 114.79 ± 6.35 <sup>c</sup>	± 49.70 ± 0.35 <sup>c</sup>	± 96.44 ± 0.35 <sup>a</sup>	± 263.51 ± 3.54 <sup>a</sup>	± 248.63 ± 8.84 <sup>a</sup>	± 71.77 ± 6.19 <sup>a</sup>	± 30.38 ± 4.42 <sup>b</sup>	± 12.65 ± 0.35 <sup>c</sup>	± 1.20 ± 0.35 <sup>c</sup>	± 10.65 ± 0.35 <sup>d</sup>	± 7.04 ± 0.35 <sup>c</sup>
	NZ.Lcc.023	1,630.48 ± 24.75 <sup>b</sup>	± 2.46 ± 0.00 <sup>b</sup>	± 163.44 ± 4.00 <sup>b</sup>	± 269.99 ± 7.07 <sup>b</sup>	± 43.01 ± 8.84 <sup>b</sup>	± 5.82 ± 0.00 <sup>b</sup>	± 90.67 ± 53.03 <sup>b</sup>	± 21.43 ± 0.00 <sup>b</sup>	± 5.32 ± 1.77 <sup>d</sup>	± 7.12 ± 0.00 <sup>d</sup>	± 0.00 ± 0.00 <sup>d</sup>	± 20.02 ± 1.77 <sup>c</sup>
NZ.Lcl.018		256.92 ± 9.19 <sup>d</sup>	± 0.95 ± 0.35 <sup>d</sup>	± 19.03 ± 0.35 <sup>d</sup>	± 36.12 ± 0.35 <sup>d</sup>	± 4.63 ± 0.35 <sup>d</sup>	± 1.55 ± 0.35 <sup>b</sup>	± 4.42 ± 0.35 <sup>c</sup>	± 5.08 ± 0.35 <sup>c</sup>	± 9.18 ± 0.35 <sup>c</sup>	± 41.45 ± 0.35 <sup>a</sup>	± 4.00 ± 0.35 <sup>a</sup>	± 88.11 ± 0.35 <sup>b</sup>
	<i>Pediococcus acidophilus</i>	1,764.15 ± 8.75 <sup>a</sup>	± 7.63 ± 0.01 <sup>a</sup>	± 275.85 ± 0.125 <sup>a</sup>	± 1,247.09 ± 2.50 <sup>a</sup>	± 23.67 ± 0.52 <sup>c</sup>	± 0.00 ± 0.00 <sup>b</sup>	± 81.74 ± 5.13 <sup>b</sup>	± 70.49 ± 3.12 <sup>a</sup>	± 38.07 ± 0.04 <sup>a</sup>	± 36.64 ± 0.75 <sup>b</sup>	± 2.29 ± 0.00 <sup>b</sup>	± 109.575 ± 5.00 <sup>a</sup>

AMN: Ammonia; HIS: Histamine; PUT: Putrescine; CAD: Cadaverine; SPD: Spermidine; TPT: Tyriptamine; PHE: 2-phenyletilamine; SPM: Spermine; SER: Seretonin; TYR: Tyramine; TMA: 3-methylamine; DOP: Dopamine; and AGM: Agmatine.

<sup>a-d</sup> Values in the same column followed by the same superscript letter are not significantly different ( $p > 0.05$ ).

the lowest value) than NZ.Lcc.023 (43.01 ppm and 5.82 ppm, respectively). The NZ.Lcl.011 exhibited the lowest TMA concentration (1.20 ppm), while NZ.Lcl.018 had the highest (4.00 ppm). *Lactococcus* isolates generally exhibited higher production of SPD, PHE, and SER compared to other genera. Notably, only *Lactococcus* accumulated TPT in HDB. The distinct amine profiles among LAB genera highlighted the complexity of these microbial communities and importance of understanding their dynamics for food safety and quality. While HIS accumulation was low in all LAB isolates compared to other ones, the findings suggested a significant variability in BA production among the various LAB genera. Notably, *Lactococcus* demonstrated a remarkable ability to produce higher amounts of AMN and specific amines like SER and TYR.

### Discussion

Each LAB genus exhibited distinct BA profiles, as evidenced by the variations in individual amine concentrations within their post-biotic solutions. Determining the ability of LAB to produce HIS, TYR, CAD,

and PUT from specific amino acids, facilitated by potential amino acid decarboxylase enzymes, is crucial for food safety because of their use as starters or bio-protective cultures.<sup>17</sup> Current work findings highlighted the diverse production of different BAs among LAB genera isolated from fish products. Notably, *Lactococcus* isolates, particularly NZ.Lcl.011, NZ.Lcl.018, and NZ.Lbp.105, demonstrated a remarkable ability to produce higher amounts of specific amines, such as SER and TYR compared to other LAB genera, with *Leuconostoc* displaying the second-highest production. The BAs play a significant role in determining the overall quality and safety of the fermented products. Therefore, determining the BA-forming ability of LAB isolates and evaluating their potential impact on food safety are crucial aspects of food control procedures.<sup>18</sup> For instance, the ability of LAB isolates to produce HIS in food products, particularly fish products, is an important consideration for ensuring food safety and quality.<sup>19</sup>

The LAB produce diverse BAs due to varying decarboxylase enzymes across different isolates. This variation is analyzed by measuring BA accumulation in cell-free post-bioticsolutions. For example, histidine

decarboxylase and lysine decarboxylase enzymes convert histidine and lysine to HIS and CAD, respectively.<sup>20</sup> Notably, Moreno-Arribas *et al.*<sup>21</sup> isolated a wine strain of *Leu. mesenteroides* capable of producing TYR, and Landete *et al.*<sup>22</sup> identified another wine strain capable of HIS production. *Enterococcus (faecium, faecalis)*, *Lactobacillus* (various isolates), and *Leu. mesenteroides* possess the HDenzyme, responsible for HIS production. This study found generally low HIS production in *Leuconostoc* isolates, except for NZLeu.009, exhibited higher accumulation (83.69 ppm). Although NZLeu.006 produced AGM (68.50 ppm), the highest accumulation of other amines varied among the isolates. Interestingly, despite having the lowest AGM production, NZLeu.009 displayed the highest accumulation of SPD, SPM, and TMA.

*Leuconostoc* spp. are found in various foods, including those of animal origin, fresh and decaying plants, and fermented vegetables. Some isolates have been associated with food spoilage, while others are beneficial.<sup>23</sup> Notably, the presence of decarboxylase enzymes has been documented in certain isolates.<sup>1</sup> The safety of using *Leuconostoc* isolates as anti-fungal bio-protectants in food products was evaluated using the TYR-producing *Leu. mesenteroides* as a model. This study highlighted the importance of testing decarboxylase activity in candidate probiotic isolates to ensure food safety.<sup>24</sup>

The presence of *Enterococci* capable of producing BAs is a significant food safety concern, even in meat products. While *Enterococci* can contribute to the sensory properties of fermented products, particularly sausages, their potential BA production necessitates careful consideration.<sup>25</sup> Untreated meat and several fermented meat products naturally harbor *Enterococci*, with *E. faecium* and *E. faecalis* being the most prevalent species.<sup>26</sup> High levels of BAs, particularly TYR, PUT, and CAD, can readily accumulate in dry fermented sausages.<sup>27</sup>

The variability in BA production among LAB isolated from different fish products underlines the complexity of microbial communities. When the mean of the amount of amines produced by the LAB members *Enterococcus* (10 isolates), *Leuconostoc* (seven isolates), *Lactococcus* (three isolates), *Lactobacillus* (six isolates) was taken within each LAB member, results showed that *Lactococcus* produced the most AMN, SER, and TYR, exceeding other genera by an average of 250 ppm. *Leuconostoc* showed higher SPD, PHE, and SER than other genera except *Lactococcus* for PHE. The TPT was only detected in *Lactococcus*. The HIS levels were negligible in all four genera compared to others. *Lactobacillus* had the highest concentrations of most BAs, except for HIS, PUT, and TMA, which were the highest in *Leuconostoc*. These results provide valuable insights into the diversity of BAs production capabilities within different LAB genera, being crucial for understanding their impact on the quality and safety of fermented products.

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## Conflict of interest

The author declares no conflicts of interest.

## References

1. Saha Turna N, Chung R, McIntyre L. A review of biogenic amines in fermented foods: occurrence and health effects. *Heliyon* 2024; 10(2): e24501. doi: 10.1016/j.heliyon.2024.e24501.
2. Dabadé DS, Jacxsens L, Micolte L, et al. Survey of multiple biogenic amines and correlation to microbiological quality and free amino acids in foods. *Food Control* 2021; 120: 107497. doi: 10.1016/j.foodcont.2020.107497.
3. Gao X, Li C, He R, et al. Research advances on biogenic amines in traditional fermented foods: emphasis on formation mechanism, detection and control methods. *Food Chem* 2023; 405(Part A): 134911. doi: 10.1016/j.foodchem.2022.134911.
4. Özogul F, Hamed I. The importance of lactic acid bacteria for the prevention of bacterial growth and their biogenic amines formation: a review. *Crit Rev Food Sci Nutr* 2018; 58(10): 1660-1670.
5. Dala-Paula BM, Custódio FB, Gloria MBA. Health concerns associated with biogenic amines in food and interaction with amine oxidase drugs. *Curr Opin Food Sci* 2023; 54: 101090. doi: 10.1016/j.cofs.2023.101090.
6. Ma X, Wang Y, Liu Y, et al. Mechanisms and factors influencing the ability of lactic acid bacteria on reducing biogenic amines in fermented food: a mini review. *LWT* 2024; 197: 115890. doi: 10.1016/j.lwt.2024.115890.
7. Alvarez MA, Moreno-Arribas MV. The problem of biogenic amines in fermented foods and the use of potential biogenic amine-degrading microorganisms as a solution. *Trends Food Sci Technol* 2014; 39(2): 146-155.
8. del Rio B, Redruello B, Linares DM, et al. The biogenic amines putrescine and cadaverine show *in vitro* cytotoxicity at concentrations that can be found in foods. *Sci Rep* 2019; 9: 120. doi: 10.1038/s41598-018-36239-w.
9. Yilmaz N, Özogul F, Moradi M, et al. Reduction of biogenic amines formation by foodborne pathogens using postbiotics in lysine-decarboxylase broth. *J Biotechnol* 2022; 358: 118-127.
10. Moradi M, Kousheh SA, Almasi H, et al. Postbiotics

- produced by lactic acid bacteria: the next frontier in food safety. *Compr Rev Food Sci Food Saf* 2020; 19(6): 3390-3415.
11. Ghorbani M, Molaei R, Moradi M, et al. Carbon dots-assisted degradation of some common biogenic amines: an in vitro study. *LWT* 2020; 136(2): 110320. doi: 10.1016/j.lwt.2020.110320.
  12. Păcularu-Burada B, Georgescu LA, Vasile MA, et al. Selection of wild lactic acid bacteria strains as promoters of postbiotics in gluten-free sourdoughs. *Microorganisms* 2020; 8(5): 643. doi: 10.3390/microorganisms8050643.
  13. EFSA Panel on Biological Hazards (BIOHAZ); Scientific opinion on risk based control of biogenic amine formation in fermented foods. *EFSA J* 2011; 9(10): 2393. doi: 10.2903/j.efsa.2011.2393.
  14. Toy N. Investigation of organic acid production, antimicrobial activity and antibiotic resistance of lactic acid bacteria identified from different foods. PhD Thesis. Çukurova University, Adana, Turkey: 2019.
  15. Özogul F. Effects of specific lactic acid bacteria species on biogenic amine production by foodborne pathogen. *Int J Food Sci Technol* 2011; 46(3): 478-484.
  16. Toy N, Özogul F, Özogul Y. The influence of the cell free solution of lactic acid bacteria on tyramine production by food borne-pathogens in tyrosine decarboxylase broth. *Food Chem* 2015; 173: 45-53.
  17. Abarquero D, Bodelón R, Flórez AB, et al. Technological and safety assessment of selected lactic acid bacteria for cheese starter cultures design: enzymatic and antimicrobial activity, antibiotic resistance and biogenic amine production. *LWT* 2023; 180: 114709. doi: 10.1016/j.lwt.2023.114709.
  18. Shiono K, Tsutsumi T, Nabeshi H, et al. Simple and rapid determination of biogenic amines in fish and fish products by liquid chromatography-tandem mass spectrometry using 2,4,6-triethyl-3,5-dimethyl pyrylium trifluoromethanesulfonate as a derivatization reagent. *J Chromatogr A* 2021; 1643: 462046. doi: 10.1016/j.chroma.2021.462046.
  19. Lee YC, Kung HF, Huang CY, et al. Reduction of histamine and biogenic amines during salted fish fermentation by *Bacillus polymyxa* as a starter culture. *J Food Drug Anal* 2016; 24(1): 157-163.
  20. Benkerroum N. Biogenic amines in dairy products: origin, incidence, and control means. *Compr Rev Food Sci Food Saf* 2016; 15(4): 801-826.
  21. Moreno-Arribas MV, Polo MC, Jorganes F, et al. Screening of biogenic amine production by lactic acid bacteria isolated from grape must and wine. *Int J Food Microbiol* 2003; 84(1): 117-123.
  22. Landete JM, Ferrer S, Pardo I. Biogenic amine production by lactic acid bacteria, acetic bacteria and yeast isolated from wine. *Food Control* 2007; 18(12): 1569-1574.
  23. Wätjen AP, De Vero L, Carmona EN, et al. *Leuconostoc* performance in soy-based fermentations - Survival, acidification, sugar metabolism, and flavor comparisons. *Food Microbiol* 2023; 115: 104337. doi: 10.1016/j.fm.2023.104337.
  24. Coton M, Lebreton M, Leyva Salas M, et al. Biogenic amine and antibiotic resistance profiles determined for lactic acid bacteria and a propionibacterium prior to use as antifungal bioprotective cultures. *Int Dairy J* 2018; 85: 21-26.
  25. Zhang Y, Shan B, Gong J, et al. Mechanism of biogenic amine synthesis of *Enterococcus faecium* isolated from Sanchun ham. *Food Sci Nutr* 2022; 10(6): 2036-2049.
  26. Anderegg J, Fischer M, Dürig J, et al. Detection of biogenic amines and tyramine-producing bacteria in fermented sausages from Switzerland. *J Food Prot* 2020; 83(9): 1512-1519.
  27. Wang H, Sui Y, Liu J, et al. Screening and evaluating microorganisms with broad-spectrum biogenic amine-degrading ability from naturally fermented dry sausage collected from Northeast China. *Meat Sci* 2024; 210: 109438. doi: 10.1016/j.meatsci.2024.109438.