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Review

# Biogenic amines and their production by microorganisms in food

Anna Halász, Ágnes Baráth, Livia Simon-Sarkadi and Wilhelm Holzapfel

This paper presents an overview of the origin and importance of biogenic amines found in foods, with special reference to biogenic amines resulting from the metabolic activities of food-associated microorganisms. Compared with foods of animal origin (e.g. milk and meat products), relatively little information is available on the levels of biogenic amines in vegetable foods and in novel and prepacked convenience foods.

Biogenic amines are low molecular weight organic bases that possess biological activity. They can be formed and degraded as a result of normal metabolic activity in animals, plants and microorganisms, and are usually produced by the decarboxylation of amino acids. Figure 1 shows the major pathways for the formation of di- and polyamines.

Several biogenic amines (serotonin, histamine and tyramine) play important roles in many human and animal physiological functions. In plants, the diamine putrescine and the polyamines spermidine and spermine are implicated in a number of physiological processes, such as cell division, flowering, fruit development, response to stress and senescence[1–3].

Biogenic amines in foods are of concern in relation to both food spoilage and food safety. They are generated either as the result of endogenous amino acid decarboxylase activity in raw food materials, or by the growth of decarboxylase-positive microorganisms under conditions favourable to enzyme activity[4]. As the microbial spoilage of food may be accompanied by the increased production of decarboxylases, the presence of biogenic amines might serve as a useful indicator of food spoilage.

Monoamine oxidases and diamine oxidases play a major role in amine degradation in the human body. Biogenic amines do not usually represent any health hazard to individuals unless large amounts are ingested, or the natural mechanism for the catabolism of the amines is inhibited or genetically deficient. Typical symptoms may be observed in certain individuals, and include nausea, sweating, headache and hyper- or hypotension[5].

The most frequent foodborne intoxications caused by biogenic amines involve histamine. Histamine poisoning is also referred to as 'scombroid fish poisoning' because of the association of this illness with the consumption of scombroid fish, such as tuna, mackerel and sardines[6]. Another phenomenon is the 'cheese reaction' caused by high levels of tyramine in cheese[7].

Determination of the exact toxicity threshold of biogenic amines in individuals is extremely difficult. The toxic dose is strongly dependent on the efficiency of the detoxification mechanisms of different individuals. Upper limits of 100 mg histamine/kg in foods, 2 mg

**Anna Halász** and **Ágnes Baráth** are at the Central Food Research Institute, Herman Otto ut 15, H-1536 Budapest, Hungary. **Livia Simon-Sarkadi** is at the Department of Biochemistry and Food Technology, Technical University of Budapest, H-111 Budapest, Hungary. **Wilhelm Holzapfel** (corresponding author) is at the Institute of Hygiene and Toxicology, Federal Research Centre for Nutrition, Engesserstr. 20, D-76131 Karlsruhe, Germany.

  

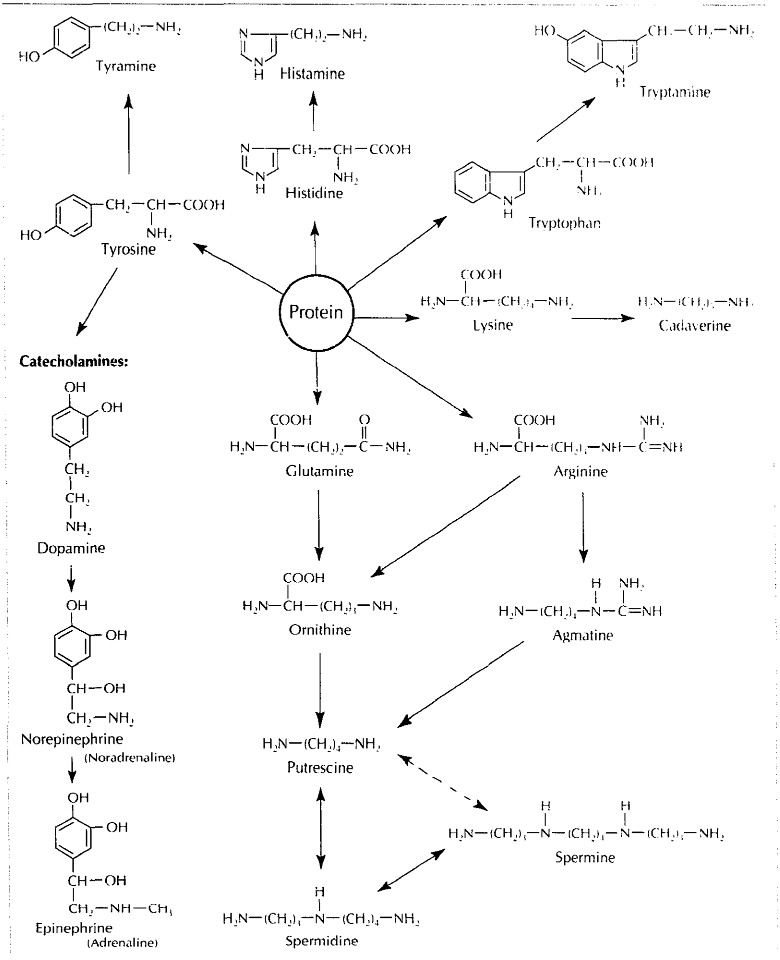


**Fig. 1**

Metabolic pathways for the formation of biogenic amines.

histamine/l in alcoholic beverages, and 100–800 mg/kg tyramine and 30 mg/kg phenylethylamine in foods have been suggested[8].

Secondary amines such as putrescine and cadaverine can react with nitrite to form carcinogenic nitrosamines[9]. For this reason it is particularly important to prevent the accumulation of biogenic amines in cured food products.

Since many countries do not keep statistical data, comprehensive reports of the worldwide occurrence of food-related intoxications caused by biogenic amines do not exist. Bartholomew *et al.*[10] reviewed over 250 suspected incidents in the UK in the period 1976–1986 and noted that the most common symptoms were rash, diarrhea, flushing, sweating and headache. Similar studies of foodborne intoxication in Canada[11], The Netherlands[12], the USA[13] and Saudi Arabia[14] have been reported.

Prerequisites for the formation of biogenic amines in foods are the availability of free amino acids, the presence of decarboxylase-positive microorganisms, conditions that allow bacterial growth, and decarboxylase activity[8]. Free amino acids occur as such in foods, but may also be liberated from proteins as a result of proteolytic activity. Decarboxylase-positive microorganisms may constitute part of the associated population of the food or may be introduced by contamination before, during or after processing of the food. In the case of fermented foods and beverages, the applied starter cultures may also affect the production of biogenic amines.

## Biogenic amine production by bacteria

The amount and type of amine formed in a food depends on the nature of the commodity and on the microorganisms present. Many Enterobacteriaceae, and certain lactobacilli (e.g. *Lactobacillus buchneri*), pediococci and enterococci are particularly active in the formation of biogenic amines. As histamine has one of the highest biological activities of all the amines, its production is of particular interest. Histidine decarboxylase activity is widely distributed in the genera *Escherichia*, *Salmonella*, *Clostridium*, *Bacillus* and *Lactobacillus*[15].

Since some people may suffer adverse reactions after consuming amines, the production of fermented foods with predictably low levels of specified amines is a goal that needs to be addressed in the future by the food industry.

Numerous bacteria have been reported to possess histidine decarboxylase activity, but only relatively few of the bacteria found in foods have been implicated as causative organisms in the formation of toxicologically significant levels of histamine. Wide variations in histamine formation have been observed even among strains of the same species.

Sumner *et al.*[16] reported that *Lactobacillus buchneri* strains in culture produce histamine at levels of <1–4070 nmol/ml, while *Lactobacillus brevis* strains produced <1–6 nmol/ml. Engesser *et al.*[17] investigated 26 authentic and isolated strains of lactic acid bacteria for histamine and tyramine production. Under the test conditions only one strain (*L. buchneri*) was found to be a strong producer of histamine, while only *Enterococcus faecalis* formed significant concentrations of tyramine. According to Teuber[18], and Voigt and Eitenmiller[15], the contaminating microflora rather than the starter cultures themselves are responsible for high biogenic amine levels. However, we have recently found that amino acid decarboxylase enzyme activities of bacteria used as starter cultures vary widely, and some even produce histamine (Baráth, Á. *et al.*, unpublished). This is in agreement with findings that several *Lactobacillus* spp. used in the food industry are known for their ability to produce biogenic amines[19,20].

Strains with high proteolytic enzyme activity probably have an increased potential for biogenic amine production in food systems. Studies of *Lactobacillus plantarum* growth in culture medium (MRS) supplemented with 0.1% histidine at 30°C indicate a relationship between increased intracellular proteolytic enzyme activity (determined using haemoglobin as a substrate) and the accumulation of histamine in the medium; histamine content increased in parallel with increased decarboxylase activity (Baráth, A. *et al.*, unpublished).

The amino acid decarboxylase enzyme activities of various *Lactobacillus* spp. are different: *L. fructivorans* had no detectable histidine decarboxylase activity, *L. brevis* var. *lindneri* had an enzyme activity of $3.7\times10^{-2}$ mol histidine/min and the activity of *L. plantarum* was $7.6\times10^{-2}$ mol histidine/min (Halász, A. *et al.*, unpublished). Amino acid decarboxylase activities were shown to depend on the composition of the medium and the growth phase of the microorganisms; the highest amino acid decarboxylase enzyme activities were detected in the stationary phase. This result is in agreement with the findings of Künsch, U. *et al.* (unpublished), who found that significant accumulation of histamine and tyramine only occurred in the final period of sauerkraut fermentation.

Amine formation by bacteria is decisively influenced by temperature: *Enterobacter cloacae* produced 2 mg/ml putrescine after 24 hours' incubation at 20°C but was unable to synthesize amine at 10°C (Skowronek, F. *et al.*, unpublished). *Klebsiella pneumoniae* was not as sensitive to temperature but did show less extensive cadaverine production at 10°C than at 20°C. The oxygen supply also appears to have a significant effect on the biosynthesis of amines. *Er. cloacae* only produced about half as much putrescine in an anaerobic situation than under aerobic conditions, and *K. pneumoniae* synthesized significantly less cadaverine but gained the ability to produce putrescine under anaerobic conditions. In food., histamine production is slowed at 10°C and nearly terminated at 5°C due to the destruction of histamine-producing bacteria at low temperatures. No histamine was formed by *Pseudomonas morganii*, *Pseudomonas vulgaris* or *Hafnia* strains after one month's incubation at 1°C.

It is evident that additional factors can also drastically influence amine formation. Early studies of amino acid decarboxylases demonstrated that the optimum pH was acidic, in the range 2.5–6.5; it was also concluded that growing bacteria in an acid medium stimulated the formation of decarboxylases[21].

The presence of fermentable carbohydrate, such as glucose, enhances both growth and amino acid decarboxylase activity in bacteria. Glucose concentrations in the range of 0.5–2.0% have been reported to be optimal, while levels in excess of 3% inhibited enzyme formation. The redox potential of the medium also influences amine production. Conditions resulting in a reduced redox potential stimulate histamine production, and histidine decarboxylase activity seems to be inactivated or destroyed in the presence of oxygen[21].

In general, investigations to date have suggested that elevated histamine levels in most foods and beverages are due to microbiological contamination, while increases in putrescine, cadaverine and tyramine concentrations are considered to correlate with bacterial starter culture activities (and counts) in particular fermented products[66].

As histamine may not be the only amine that is harmful to sensitive individuals, and since some biogenic amines may have a synergistic effect[6,22], food producers should optimize the technology and storage conditions used to secure low amine levels in foods.

## Biogenic amine content of foods

Early techniques for the determination of biogenic amines in foods were based on thin-layer chromatography[23,24]. More modern analytical techniques have since been developed that enable the acquisition of reliable quantitative data and better separation/resolution of various amines. The quantitative determination of biogenic amines is generally accomplished by overpressure-layer chromatography[25], high-performance liquid chromatography[26,27] and gas chromatography[28,29]. The simplest method for the determination of biogenic amines in foods is by chromatography on an amino acid analyser[30–33]. Additional detection techniques, such as fluorometry[34] and high-voltage electrophoresis[35,36], may also be useful.

The following solvents have been suggested for the extraction of biogenic amines: 0.6 N perchloric acid[26,29], 5–10% trichloroacetic acid[37,38], 0.1 N HCl (Refs 23, 39) and methanol[39,40]. The relative extraction efficiencies of these solvents depend on the type and nature of the amines and the foods from which they are being extracted.

### Meat

Zee *et al.*[38] quantified the levels of biogenic amines found in samples of fresh and processed pork meat. Both products contained high levels of adrenaline, spermidine and spermine (up to 581, 280 and 685 mg/kg, respectively), but low levels of noradrenaline, putrescine, histamine, cadaverine and tyramine.

Sayem-El-Daher *et al.*[41] analysed the levels of biogenic amines in cooked and uncooked ground beef stored at 4–10°C. The concentrations of putrescine, 1,3-diaminopropane, spermine, spermidine, cadaverine and tyramine were all positively correlated with both the time and temperature of storage. Histamine levels were apparently unaffected by the storage conditions. Amine concentrations were also unaffected by cooking, with the exception of spermine; spermine levels decreased during heat treatment.

The possible bacterial sources of putrescine and cadaverine in chill-stored vacuum-packed beef were studied by Dainty *et al.*[20] Added *Hafnia alvei* and *Serratia liquefaciens* cultures were both able to produce diamines during growth on beef stored in vacuum packs at 1°C.

Investigation of the biogenic amine content of pork meat during storage at different temperatures[42] showed that putrescine and cadaverine contents increased during storage, while spermidine and spermine contents decreased (Table 1). This phenomenon could be due to the differences in the reaction rates of amine synthesis and amine deamination. Putrescine, cadaverine, spermidine and spermine levels changed less during storage at –20°C than at 5°C.

Several trials have been conducted in an attempt to determine whether levels of particular amines in certain foods can be correlated with bacterial counts. The relationship between microbial quality and biogenic amine content has been widely studied in fermented foods such as cheese[28], sauerkraut[43], beef[44], wine[45] and meat[41].

**Table 1. Biogenic amine content of pork meat (mg/kg)[a]**

| | | Storage at 5°C | | Storage at –20°C | |
|---|---|---|---|---|---|
| Amine | Fresh meat | 8 days | 15 days | 8 days | 15 days |
| Putrescine | 7.8 | 16.9 | 18.9 | 9.4 | 11.2 |
| Histamine | 4.7 | 4.0 | 9.9 | 0.5 | 0.5 |
| Cadaverine | 13.3 | 38.6 | 43.0 | 27.5 | 41.2 |
| Spermidine | 7.0 | 2.3 | 3.1 | 4.6 | 4.3 |
| Spermine | 67.1 | 42.2 | 31.2 | 58.6 | 42.8 |

[a] Data taken from Ref. 42

For ground beef, putrescine shows potential for use as a bacterial index, while 1,3-diaminopropane levels do not significantly correlate with total bacterial counts[46]. Linear, quadratic and geometric models correlating putrescine levels and bacterial counts in beef have been evaluated; the best-fit equation with the highest determination coefficient ($r^2$) was the quadratic one. Using the equation, it was calculated that only 20 mg of putrescine/kg ground beef implies the presence of a total aerobic count of $10^5$ bacteria/g.

For psychrotrophs a threshold level of $10^5$–$10^6$ bacteria/g (before the spoilage stage) is required to produce significant amounts of putrescine. For coliforms the only positive correlation ($r = 0.91$) found was between bacterial counts and cadaverine levels in ground beef spoiled by a coliform count exceeding $10^5$/g. Slemr[47] found a high correlation between cadaverine levels and counts of Enterobacteriaceae spp. These data suggest that putrescine and cadaverine may be useful as direct count indicators.

On the other hand, it is well known that not all pathogenic or meat-spoilage bacteria produce decarboxylases that yield putrescine. Slemr and Beyermann[48] found variable amine concentrations in species with similar bacterial counts. These concentration differences can be explained by different biochemical potentials for metabolizing amino acids of the organisms. The breakdown of diamines is a contributory factor in the variance of the putrescine and cadaverine contents. *Pseudomonas* strains that are known to be the dominant microorganisms in chilled meats mainly produce putrescine, whereas strains of the Enterobacteriaceae preferentially form cadaverine.

### Fish

Tuna and related fish ('scombroid fish') have been most commonly noted to contain elevated levels of histamine, and these have been associated with incidents of histamine intoxication. The tissues of scombroid fish contain high levels of free histidine, which may be converted into histamine by associated microorganisms[8]. The levels of free amino acids usually increase in fishery products during storage due to the action of endogenous and exogenous proteases[49]. A total of 14 bacterial species with histidine decarboxylase activity were isolated from decomposing fish[50]. A correlation was found between increasing total microbial counts and rising amine levels. According to Klausen and Lund[51] the amine contents depend on the temperature. At 10°C the amine contents were 2–20 times higher than at 2°C, in both mackerel (a scombroid fish) and herring (a non-scombroid fish). *K. pneumonia*, *Morganella morganii* and *H. alvei* appeared to be responsible for the high histamine levels in fish[52].

Several studies of psychrophilic halophiles (bacteria that thrive in cold, salty water), which occur as part of the normal microbial population of marine fish, revealed their ability to produce high amounts of histamine at temperatures as low as 2.5°C (Ref. 53). In addition, Ababouch *et al.*[54] indicated that low storage temperatures are not sufficient to inhibit the formation of toxic amines such as histamine.

## Cheese

Cheese is one of the foods with the highest amine content. Levels of the biogenic amines histamine and tyramine have been investigated in different cheeses. Cheddar cheeses have been found to be especially rich in amines; tyramine levels as high as 1500 mg/kg have been reported[55]. Particularly high levels of biogenic amines have been found in the rinds of various cheeses[22]. The tyramine is probably formed by aerobic bacteria and not by the lactobacilli added for cheese manufacture. Phenethylamine occurs in variable concentrations in Cheshire and Edam cheeses. Gouda cheeses were found to contain elevated levels of histamine[22,55]. De Koning[56] reported that contaminant lactobacilli present in the rennets used were responsible for the formation of toxic levels of histamine in Gouda cheese.

As the amine-producing abilities of various bacteria differ widely, no direct correlation could be found between the histamine and tyramine contents and bacterial counts. Scienzynska, H. *et al.* (unpublished) have shown that in 18 of the 53 samples examined, numbers of Enterobacteriaceae exceeded $10^5$/g, and in 21 of the samples *Enterococcus* counts were $>10^5$/g. Despite this fact only 2 samples showed high concentrations of histamine and tyramine.

Table 2 shows the amine contents of some European cheeses. High levels of histamine were reported in several varieties.

## Sauerkraut

The effect of fermentation conditions on histamine formation in sauerkraut has been studied by Mayer *et al.*[57] It was found that histamine levels in sauerkraut could increase to 160 μg/g after fermentation for 10 weeks. Taylor *et al.*[43] found histamine concentrations of up to 130 μg/g in 50 sauerkraut samples. Baráth and Halász[58] investigated 8 commercial sauerkraut samples. The data in Table 3 show that biogenic amines, especially putrescine, accumulated in sauerkraut brine.

## Beer

The distribution of biogenic amines has been investigated in 40 Italian beers and in 2 samples of hop extract. Cadaverine and phenylethylamine were present occasionally; levels did not exceed 0.5 and 0.7 ppm, respectively. Tryptamine (7.5 ppm) and putrescine (5 ppm) were also found, but no histamine[59].

The influence of *L. brevis* and *Saccharomyces uvarum* on biogenic amine contents in fermented and unfermented worts has been studied[31]. *L. brevis* produced putrescine and tyramine, but reduced the agmatine content in worts; while *S. uvarum* did not produce amines. We have investigated the influence of technological conditions of beer production on biogenic amine formation. Barley variety, malting technology, wort processing and fermentation conditions seem to affect the total biogenic amine content of beer. Histamine content, however, is always an indicator of microbial contamination in beer, as malt itself possesses no histidine

**Table 2. Biogenic amines in some European cheeses (mg/kg)**

| Country of origin | Type (number of samples) | Histamine | Tyramine | Tryptamine | Phenylethylamine | Cadaverine | Putrescine |
|---|---|---|---|---|---|---|---|
| The Netherlands[a] | Maasdamer (246), Gouda (77) | 77–246 | 65–417 | ND | ND | 97–1142 | 13–3542 |
| Italy[a] | Parmesan | 272 | 64 | ND | ND | 98 | 43 |
| Germany[a] | Spoiled Gouda, Harzer | 247–305 | 23–339 | 881 | 72–92 | 46–995 | 44–1071 |
| Denmark[a] | Höhlenkäse | 230 | 123–532 | ND | ND | 87–102 | 159–200 |
| France[a] | Emmental, Raclette, Roquefort | ND | 132–287 | ND | 75–81 | 96–133 | 96–237 |
| Switzerland[a] | Tête de Moine (37), Appenzeller (708) | 37–708 | 74–558 | ND | 67 | 117–274 | 38–1324 |
| Hungary[b] | Mischi (67), Pannonia (320) | 67–320 | ND | ND | ND | 24–58 | 60–164 |

[a] Data taken from Ref. 17. Note that different sampling procedures and detection methods were used for the data from each country.
[b] Data taken from Ref. 42
ND, Not determined

Table 3. Biogenic amine content of sauerkraut and brine[a]

| Amine | mg/kg Sauerkraut | mg/l Brine |
|---|---|---|
| Putrescine | 100–200 | 442–678 |
| Histamine | 42–52 | 143–174 |
| Cadaverine | 53–71 | 178–237 |
| Spermidine | 3–8 | 10–76 |
| Spermine | 1–2 | 3–5 |

[a] Data taken from Ref. 55

decarboxylase activity and histamine has not been found in brewer's yeast. Although histamine does not appear to be present in pure brewer's yeast, pitching yeast is often contaminated with *Lactobacillus* strains. As the histamine-producing ability of bacteria vary greatly and not only living cells but also active enzymes from lysed bacteria possess catalytic activity, no direct correlation could be found beween histamine concentration of beer and viable *Lactobacillus* counts of wort, pitching yeast or unfiltered beer. Depending on malting and brewing technology the total biogenic amine content of beer can vary in the range of 15–60 mg/l (Halász, Á. *et al.*, unpublished).

## Fruit and vegetables

In plants arginine is decarboxylated to agmatine, and putrescine is formed from agmatine[22]. In conditions of potassium and magnesium deficiency and high ammonium concentrations agmatine and putrescine accumulate in plants. Considerable variation in estimated amine content is associated with different degrees of maturity, so very different amine concentrations have been published for the same type of fruit.

High amine levels have been found in orange juice (noradrenaline, tryptamine), tomato fruit (tyramine, tryptamine, histamine), banana fruit (tyramine, noradrenaline, tristamine, serotonin), plum fruit (tyramine, noradrenaline) and spinach leaves (histamine)[24].

Phenethylamine in chocolate is derived from the roasted cocoa bean and its concentration in the final product varies considerably. Concentrations in raw beans, low-, medium- and high-roast beans are <2, 9, 10 and 12 mg/100 g respectively, which are consistent with the formation of this amine by decarboxylation of phenylalanine during roasting[60].

Microbial contamination results in further increases in the biogenic amine contents of fruits and vegetables.

Microbiological studies of vegetables indicate that bacteria comprise the predominant group of microorganisms, although lower numbers of moulds and yeasts are also present. On the basis of colony appearance *Pseudomonas* spp., *Erwinia herbicola*, *Erwinia carotovora*, the *Enterobacter agglomerans* group, and *Serratia* spp. were found to be commonly present in lettuce[24]. A wide variety of yeast species have also been isolated from fresh lettuce. The yeast species most frequently isolated from lettuce included members of the genera *Candida*, *Cryptococcus*, *Pichia*, *Torulaspora* and *Trichosporon*. Comparatively few moulds were isolated from lettuce[61].

The microbial population of fruits differs from that of vegetables. The low pH of most fruits restricts the microbial association to acid-tolerant microorganisms, such as fungi and lactic acid bacteria[62].

Fresh, whole fruits and vegetables are protected from microbial invasion by their peels or skins. Products with cut surfaces (e.g. shredded or sliced prepacked salads) are more perishable. Despite the relative safety of fresh fruits and vegetables, foodborne diseases can and do occur[63].

The microbial population and biogenic amine content of 'ready-to-use' vegetables have been recently investigated. Putrescine, histamine, cadaverine, spermidine, agmatine, spermine and tyramine were detected at different concentrations depending on the type of sample (10–30 µg/g fresh salad, 100–300 µg/g fresh sprout). Preliminary results suggest that a positive correlation exists between the Enterobacteriaceae population (representing up to 90% of the total microbial numbers) and the putrescine concentration (Simon-Sarkadi, L. and Holzapfel, W.H., unpublished). This finding differs from the observations made by Slemr and Beyermann[48], who reported that Enterobacteriaceae strains preferentially form cadaverine and *Pseudomonas* strains mainly synthesize putrescine. The difference could either be explained by the different amino acid composition of vegetables (salads and sprouts) and meat or that the contaminating Enterobacteriaceae strains differ in their amino acid decarboxylase activities.

Although most studies confirm the potential usefulness of amines as indicators of food quality[47,64], information on the levels of biogenic amines in a number of product groups, including leafy vegetables and vegetable sprouts, is still lacking. We have examined the biogenic amine content and microbial quality of prepacked salad mixtures and fresh leafy vegetables during storage at 5°C for 6 days. Among the biogenic amines detected the putrescine concentration markedly and continuously increased during storage (Fig. 2) in most of the species studied. The total bacterial population, dominated by the Enterobacteriaceae, reached a maximum of between $4\times10^6$ and $4\times10^7$ cfu/g in leafy vegetables by the end of the 6-day storage period. Depending on the type of sample, the biogenic amine content ranged from 10 to 30 µg/g of fresh salad. A relationship appears to exist between the Enterobacteriaceae population and the putrescine concentration of prepacked salad mixes (Simon-Sarkadi, L. *et al.*, submitted).

We have also investigated the biogenic amine content relative to microbial activities in mung bean, lentil and radish sprouts in prepacked and 'home-made' products[65]. In prepacked retail products the total biogenic amine content was twice as high as in 'home-made' samples. The total bacterial count reached a maximum of between $4\times10^8$ and $4\times10^9$ cfu/g in the sprouts investigated. Enterobacteriaceae and *Pseudomonas* species were the

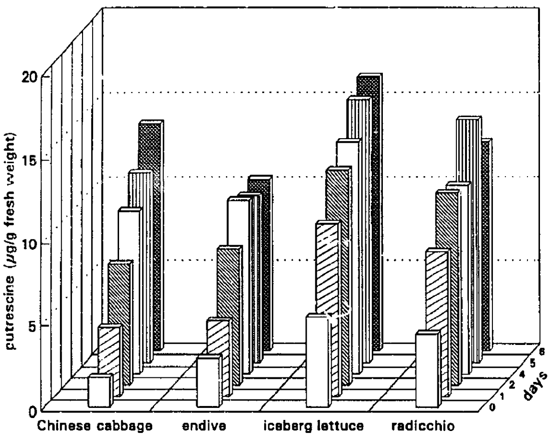


Fig. 2
Changes in putrescine content in leafy vegetables packaged in polyethylene bags during storage in a normal atmosphere at 5°C for 6 days, as determined by an amino acid analyser (Simon-Sarkadi, L. *et al.*, submitted).

dominant groups. In leguminose sprouts *Er. cloacae* in particular seems to be associated with putrescine levels, and *K. pneumoniae* with cadaverine production.

## Conclusions

Putrescine, spermidine and spermine probably occur universally in animals and plants, and at least putrescine and spermidine are found in most bacteria. These amines are important in the regulation of nucleic acid function and protein synthesis, and probably also in the stabilization of membranes.

Certain classes of amines, the catecholamines, indolamines and histamine, fulfil important metabolic functions in humans, especially in the nervous system and the control of blood pressure. Phenethylamine and tyramine cause a rise in blood pressure; by contrast histamine reduces the blood pressure. Histamine possesses a powerful biological function, serving as a primary mediator of the immediate symptoms noted in allergic responses. The mediation of allergic reactions is an example of the toxic potential of histamine. Putrescine, cadaverine and agmatine have been identified as potentiators that enhance the toxicity of histamine to humans by depressing histamine oxidation. The rapidity of the reaction, in some cases within 5 min, suggested that absorption of at least part of the amine may take place through the oral mucous membrane, bypassing the intestinal aminooxidases.

Under normal conditions in humans exogenous amines absorbed from food are rapidly detoxified by the action of amine oxidases or by conjugation, but in the case of allergenic individuals or if monoamine oxidase inhibitors are applied the detoxification process is disturbed and biogenic amines accumulate in the body.

Although other biogenic amines are much less toxic than histamine, the nitrosable secondary amines (agmatine, spermine, spermidine) can form nitrosamines by reaction with nitrite and produce carcinogenic compounds[22].

Furthermore, the estimation of the biogenic amines histamine, tyramine, agmatine, putrescine, cadaverine, spermidine and spermine is important not only from the point of view of their toxicity, but also because they can be used as indicators of the degree of freshness or spoilage of food.

Diamine concentration correlates better with total viable cell counts than with counts of Gram-negative bacteria. The relatively poor correlation between amine content and cell count is caused by variations in bacterial strain. Even strains of the same species show differences of up to three orders of magnitude in amine production.

Until now there has been no systematic investigation of the biogenic amine content of various foods. Most data that have been published relate to meat, fish, cheese and some sporadic investigations on the amine production of certain bacteria isolated from foods. The analytical methods applied by the various research groups have varied widely, both for sample preparation and separation techniques and the methods used to detect the individual amines, so that it is difficult to compare the data.

Biogenic amines are endogenous constituents of cells and therefore of food raw material and their levels can vary widely depending on variety, maturity and environmental conditions. Relative to the original concentration the levels can change during food processing and storage and are influenced by hygienic conditions.

A systematic follow-up of the effect of each processing step on biogenic amine levels can result in an optimized technology for low biogenic amine content food productions including selection of raw material and will enable food chemists to declare limiting amine concentrations for certain food products. Selection criteria of bacteria used for starter cultures should include the amine production, (especially histamine) of the microorganisms. Elevated levels of histamine or detectable amounts of this highly active compound are in most cases due to microbial contamination and not an endogenous constituent. Further investigations will be necessary to confirm this finding.

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