Aroma Constituents and Enzyme Activities of Japanese Long Coriander Leaves

(Culantro, Eryngium foetidum L.)

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Long coriander leaves (Eryngium foetidum L.) have become increasingly familiar as culinary herbs in Japan. To investigate the overall aroma characteristics of Japanese long coriander, the volatile composition from different extraction methods was investigated by GC, GC-MS, and GC-O. (E)-2-dodecenal with fruity, sweet and sour notes was found as the major component with the highest flavor dilution factor independent of the extraction methods, and played an important role in the aroma quality. Moreover, the existence of aliphatic aldehyde reductase and aldehyde dehydrogenase was found for the first time in the long coriander herb. The formation of alcohols and acids from their corresponding aldehydes in the volatile concentrate due to the enzymatic activities was observed and found to affect the overall odor of the herb.

Keywords: Japanese long coriander, Eryngium foetidum, aroma constituents, aliphatic aldehyde reductase, enzyme activities

Introduction

The long coriander plant (culantro, Eryngium foetidum L.), a member of the Umbelliferae family from Central America, is now grown and consumed as a herb or a spice in many parts of the world. The herb has long and tough leaves with an aroma which is very similar to the aroma of common coriander (cilantro, Coriandrum sativum L.). In Asia, the long coriander herb is commonly used with cilantro in soups, noodle dishes and curries. Recently, the herb is also cultivated in Japan and has become increasingly familiar among Japanese.

Most previous studies on the oil composition of long coriander applied the hydrodistillation method to isolate the aroma concentration of the herb. The essential oils from the seed (Pino et al., 1997), roots (Wong et al., 1994), and leaves (Cardozo et al., 2004; Pino et al., 1997; Wong et al., 1994) of long coriander were reported to be rich in aliphatic aldehydes, most of which are unsaturated. The major component proportions of the essential oils from the leaves cultivated in Venezuela (Cardozo et al., 2004) and Cuba (Pino et al., 1997) were reported to be different. The monoterpene hydrocarbon fraction in the Venezuelan oil was much larger than that reported in the Cuban oil. Meanwhile, the oils of long coriander cultivated in Malaysia (Wong et al., 1994) and Vietnam (Leclercq et al., 1992) were reported to have very high (E)-2-dodecenal content (59.7% and 45.5%, respectively). Recently, Cadwallader et al. (2005) used a cold direct solvent extraction method and reported that (E)-2-dodecenal was the major constituent comprising over 55% of the total volatiles, followed by several 2-alkenals (about 15%), (E)-2-dodecenoic acid (9.3%), dodecanal (5.8%), and dodecanoic acid (4.9%). These findings showed that the origin of the herb, the sample preparation and the extraction method had significant effects on the aroma composition and variability in the results. Cilantro mimics having a distinct flavor composed of coriander (Coriandrum sativum L.), long coriander (Eryngium foetidum L.), and Vietnamese coriander (Persicaria odoratum Lour.) are known as culinary and medicinal herbs and are used in the same manner in various cultures. In our previous study on coriander (To Quynh et al., 2010) and Vietnamese coriander (To Quynh et al., 2009), an enzymatic
activity comprising aliphatic aldehyde reductase and aldehyde dehydrogenase was first confirmed to be responsible for the differences in the volatile composition of the herbs. These enzymes catalyze the reduction of aliphatic aldehydes to their corresponding alcohols depending on the coenzyme, NADH or NADPH, used in the reaction mixture. The enzyme activities influence the flavor quality of coriander and Vietnamese coriander during food processing. In addition, the mentioned herbs differ in their scientific and generic name, which explains the differences in the volatile composition and enzyme activity between the two herbs. Long coriander, which belongs to the same Umbelliferae family of corianders, is therefore assumed to have similar enzymatic activity to the other coriandersons.

The purposes of the present study were to clarify the overall aroma characteristics of Japanese long coriander when it is used as a herb and to investigate the occurrence of an enzymatic activity in the herb which could affect its odor characteristics. The obtained results are also expected to expand the utilization of the herb and to show similarities or differences in the changes of the volatile composition due to the enzyme activity among three types of cilantro mimics.

Materials and Methods

Chemicals

The following compounds were obtained commercially from Wako Pure Chemical Industries (Osaka, Japan): (Z)-3-hexenol, 2-ethylhexanol, decanol, docoanal, (E)-2-dodecenol, decanoic acid, dodecanoic acid, (E)-2-dodecanoic acid, hydrocarbons of C6 to C26, α-pinene, sabinene, β-pinene, limonene, γ-terpinene, α-bergamotene, β-bisabolene, β-farnesene, β-caryophyllene, carbitol, (E)-nerolidol, 4-vinylphenol, indole, vanillin, NAD, NADP, NADH, NADPH, all buffers and DMSO. Heptanal, heptanol, p-hydroxymercurybenzoate, and polyvinylpyrrolidone were purchased from Aldrich Chemicals (USA), while ethyl nonanoate was purchased from Tokyo Kasei Kogyo (Tokyo, Japan). Alkanals and (E)-2-alkenals of C10 to C14 were provided by T. Hasegawa Co., Ltd. (Tokyo, Japan).

All buffers were adjusted to the desired pH value at room temperature. NADH/NADPH and NAD/NADP were dissolved in Milli-Q (MQ) water at certain concentrations and prepared immediately prior to use. Water-insoluble chemicals were dissolved in absolute dimethyl sulfoxide (DMSO) and diluted with water. The presence of DMSO in the reaction mixture showed no effect on the enzyme activity.

Plant material

Long coriander leaves grown in Chiba Prefecture (Japan) were purchased at a local market.

Isolation of the aroma concentrate

Solvent extraction

To reduce enzyme decomposition, fresh leaves (10 g) were immersed in liquid nitrogen. After the frozen leaves had been grounded into a fine powder with a mortar and pestle, organic compounds were extracted by methanol three times. The obtained extract was adjusted to 10% methanol aqueous solution with MQ water, being subjected to chromatography in a column packed with 20 g of Porapak Q resin (Waters, 50/80 mesh). After washing the water-soluble compounds with 200 mL of MQ water, the absorbed aroma compounds were eluted with 200 mL of a mixture of pentane and diethyl ether (1:1). After desorption, 3 μg of ethyl nonanoate in diethyl ether was added as an internal standard (IS). The elute was dried over anhydrous sodium sulfate and filtered. The solvent was evaporated at 39.5°C at atmospheric pressure to obtain the aroma concentrate. The volatile compounds were then concentrated in a nitrogen stream to 20 μL just before injecting to GC.

Hot water extraction

To reproduce the aroma characteristics of long coriander that is similarly used in hot soups and noodle dishes, fresh leaves (10 g) were cut into approximately 1 cm in length, suspended in 1 L of boiling water for 2 min, and then filtered. The filtrate was cooled to room temperature, and then subjected to chromatography in a column packed with 20 g of Porapak Q resin. The aroma concentrate was obtained in the same way as that described above.

Sensory Evaluation

A panel consisting of 12 females between 21-26 years old was recruited from Food Chemistry Laboratory, Ochanomizu University, Japan. All panelists were trained in orthonasal recognition based on a selection of aroma compounds taken from a stock of some odor-active compounds related to “cilantro flavor”. They were also enrolled in a training program to detect and identify sensory attributes of the long coriander herbs, in order to ensure that they shared common perceptions on the intensity rankings of all odor qualities rated. They were asked to evaluate the odor characteristics of the herb using 11 attributes (Fig. 1) and to rate the intensity using a 10-cm line scale (0: absent; 10: strong). The samples were presented in a random order to each panelist. The data were analyzed by a Tukey’s multiple comparison test.

Sample preparation of fresh leaves

To obtain the fresh aroma of long coriander, the leaves (1 g) were cut into approximately 1 cm in length and immediately placed into a 50-mL glass bottle (with a plastic screw cap) for sensory evaluation.

Sample preparation for hot water extraction

The sample was prepared in the same way as the extraction method for isolating aroma concentrate with the same concentration. The aqueous solution (20 mL) was served to each panelist in a 50-mL glass bottle (with a plastic screw cap) for sensory evaluation.

Preparation of crude enzyme solution

Acetone powder
Cholinic acid assay. Aliphatic aldehyde reductase assay was used as a substrate, and the formation of the corresponding alcohol was recorded and quantitatively analyzed by GC. The standard assay was conducted in the same manner as described in our previous study (To Quynh et al., 2010).

The enzyme was incubated with co-enzyme for 2 min prior to adding the substrate to initiate the reaction. The effects of temperature (25 and 37°C) were investigated in the pre-experiment and the results showed that the temperature sensitivity of the enzyme activity was not apparent. Therefore, the following assays were conducted at 37°C at pH ranging from 5.0 to 10.0 in Na-phosphate or glycine-NaOH buffer.

The standard assay contained 400 μL of 250 mM buffer, 200 μL of MQ water, 100 μL of 10 mM NADH or NADPH, 250 μL of the enzyme solution, and 50 μL of 20 mM heptanal at a total volume of 1 mL. The enzyme reaction was stopped by adding sodium chloride at a concentration of 15% to extract was prepared in the same manner as reported previously (To Quynh et al., 2009), in which all steps were conducted in a cold room at 4°C. Leaves (100 g) frozen in liquid nitrogen were milled and dipped in cold acetone (−15°C). After homogenizing for 1 min by a blender, the acetone layer was removed by filtration. The process was conducted eight times, and the residue was dried under reduced pressure. The yield of the resulting acetone powder was 7.17 g, and it was kept at −80°C until used.

Each acetone powder sample (1 g) was homogenized twice for 30 s with 30 mL of 100 mM Tris-HCl buffer (pH 8.0, 4°C) containing 10% glycerol, 5 mM dithioerythritol, 2% polyvinylpyrrolidone, and 5 mM sodium hydrosulfite. The slurry mixture was centrifuged twice at 22,500 × g (20 min, 4°C), and the resulting supernatant was used as the crude enzyme solution in an assay for enzyme activity after it was diluted appropriately with buffer. The protein content was 3.1 mg/mL in the crude enzyme solution measured by the bicinonic acid assay.

Aliphatic aldehyde reductase assay  Aliphatic aldehyde was used as a substrate, and the formation of the corresponding alcohol was recorded and quantitatively analyzed by GC. The standard assay was conducted in the same manner as described in our previous study (To Quynh et al., 2010). The enzyme was incubated with co-enzyme for 2 min prior to adding the substrate to initiate the reaction. The effects of temperature (25 and 37°C) were investigated in the pre-experiment and the results showed that the temperature sensitivity of the enzyme activity was not apparent. Therefore, the following assays were conducted at 37°C at pH ranging from 5.0 to 10.0 in Na-phosphate or glycine-NaOH buffer.

The standard assay contained 400 μL of 250 mM buffer, 200 μL of MQ water, 100 μL of 10 mM NADH or NADPH, 250 μL of the enzyme solution, and 50 μL of 20 mM heptanal at a total volume of 1 mL. The enzyme reaction was stopped by adding sodium chloride at a concentration of 15% to extract

<table>
<thead>
<tr>
<th>Table 1. Effect of odor active compounds on the odor profile of Japanese long coriander leaves.</th>
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<td><strong>Compound</strong></td>
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<td><strong>Aldehydes</strong></td>
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<td>Dodecanol</td>
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<td>2-Ethylhexanol</td>
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<td>(E)-2-Dodecanol</td>
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<td>(E)-2-Dodecanoic acid</td>
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<td><strong>Total</strong></td>
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*a Odor quality perceived at the sniffing port; *b Values of compounds per 100 g of fresh herb, calculated using the calibration curves for authentic samples; *c Flavor dilution factors (FD); *d Solvent extraction method; *e Hot water extraction method; *f Value of the compound per 100 g of fresh herb, calculated using the calibration curves for an authentic sample of (E)-2-dodecenal; *g Values of compound per 100 g of fresh herb, calculated using calibration curves for an authentic sample of (E)-2-tridecenal; *h is the ± standard deviation, n = 3; *i nd : not detected.
the volatiles easily by organic solvent, and cooled in ice bath. After the addition of ethyl nonanoate as an internal standard, the formed alcohols and remaining aldehydes were extracted with pentane:diethyl ether (6:4, 1 mL), and the extract was subjected to GC analysis. The control was prepared similarly to the standard assay, but the enzyme solution was boiled before it was added to the mixture.

The reverse reaction, i.e., the dehydrogenation of alcohol to its corresponding aldehyde, was assayed at pH ranging from 5.0 to 10.0 in Na-phosphate or glycine-NaOH buffer containing NAD/NADP using heptanol as a substrate. The formation of heptanal was recorded and quantitatively analyzed by GC.

**Aliphatic aldehyde dehydrogenase assay**  The same enzyme assay as that described above was performed at varied pH but with the addition of NAD or NADP instead of NADH or NADPH. Heptanal was used as a substrate, and the formation of heptanoic acid was recorded and quantitatively analyzed by GC. The standard assay contained 400 μL of 250 mM buffer, 200 μL of MQ water, 100 μL of 10 mM NAD or NADP, 250 μL of the crude enzyme solution, and 50 μL of 20 mM heptanol at a total volume of 1 mL in sealed reaction vials. The solution was incubated at 37°C for 1 h. The enzyme reaction was stopped and extraction of the enzyme reaction products was performed in the same manner as described above. The control was prepared similarly to the standard assay, but the enzyme solution was boiled before it was added to the mixture.

The reverse reaction was also assayed at pH ranging from 5.0 to 10.0 similarly to the procedure mentioned above. However, NADH/NADPH was added instead of NAD/ NADP. Heptanoic acid was used as a substrate and the formation of heptanal in the reaction mixture was examined.

**GC and GC/MS analyses**  Volatile compounds of the samples were separated by GC, using an Agilent GC 6890 instrument equipped with a flame-ionization detector (FID) and a fused silica capillary column: DB-WAX column, 60 m × 0.25 mm i.d., and 0.25 μm film thickness (J&W Scientific, USA). Helium was used as the carrier gas at a flow rate of 1.8 mL/min. The oven temperature was held at 60°C for 4 min and then increased to 220°C at a rate of 2°C/min. The oven temperature for the enzyme experiments was programmed from 80°C to 220°C at a rate of 4°C/min. The injector and detector temperatures were set at 200°C and 220°C, respectively. To identify the volatile compounds of the sample, GC/MS was used with an Agilent-MSD-5973 mass selective detector. The GC conditions were similar to those of the GC analysis mentioned above. Each compound was identified by the agreement of its Kovats’ GC retention index (KI) and mass spectrum with those of the authentic compound.

**Quantitative analysis**  The samples were analyzed by two trained sniffers. The flavor dilution (FD) factors of the potent odor compounds in the aroma concentrate were determined by an aroma extract dilution analysis (AEDA) described by Guth and Grosch (Guth and Grosch, 1993). The GC-O conditions were the same as those described for the GC and GC/MS analyses, with the exception of the column size (60 m × 0.53 mm i.d., and 1 μm film thickness). The flow rate of helium carrier gas was 8.3 mL/min. The effluent was split into equal parts at the end of the column, each part being respectively conveyed to an FID and a sniffing port.

**Results and Discussion**

**Odor profiles**  Sensory evaluation was conducted to characterize the odor of fresh Japanese long coriander and the odor of hot water extract of the leaves. Eleven attributes were selected for the odor evaluation. The odor profiles are shown in the radar chart (Fig. 1). The odor profiles of both fresh leaves and hot water extract were characterized by the following attributes: citrusy (grapefruit, lemon), orange-like (reminiscent of orange fruit note), fruity sweet (fruity sweet odor), sour (sourness), woody (wet wood-like), green (grassy green), extending (aroma sensation is wide spreading), refreshing (generates pleasant feeling), mild (non-irritating, comfortable feeling), pungent (strong odor; stimulus odor), and boiled potato-like (reminiscent of boiled potato odor).

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**Fig. 1.** Odor profiles of a fresh leave and the hot water extract of Japanese long coriander. Asterisks indicate a significant difference between two samples (*: p < 0.05; **: p < 0.01). The meaning of the odor attributes is as follows: citrusy (grapefruit, lemon), orange-like (reminiscent of orange fruit note), fruity sweet (fruity sweet odor), sour (sourness), woody (wet wood-like), green (grassy green), extending (aroma sensation is wide spreading), refreshing (generates pleasant feeling), mild (non-irritating, comfortable feeling), pungent (strong odor; stimulus odor), and boiled potato-like (reminiscent of boiled potato odor).
samples shared similarities which were characterized as citrusy, orange-like, fruity-sweet, sour, and extending notes. However, the fresh leave sample had stronger woody, green, refreshing, mild and pungent odors (Fig. 1), whereas boiled potato-like odor could only be perceived in the hot water extract.

**Volatile profiles resulting from different extraction methods** In order to clarify the key aroma compounds which explain the similarities and differences in the aroma profiles, the main volatile components and the odor active compounds of each sample were investigated by GC, GC-O and GC-MS analyses and summarized in Table 1. The aroma compounds of long coriander composed mainly of 2-alkenals with traces of n-aldehydes, in which (E)-2-dodecenal with fruity, sweet and sour, cilantro odors was the major component of the herb independent of the extraction methods. These findings are in agreement with previous studies (Cadwallader et al., 2005; Cardozo et al., 2004, Leclercq et al., 1992; and Pino et al., 1997). However, in our experiment, there was a difference in the content of the main volatile components from the two extraction methods. Moreover, from the results of GC-O and AEDA, among the 19 odor compounds with a high FD factor, 8 key odorants including C10-C14 unsaturated and C10-C12 saturated aldehydes characterized by orange-like, fruity sweet and cilantro-like aromas were thought to have contributed most to the overall aroma of Japanese long coriander independent of the extraction method. Among these aldehydes, (E)-2-dodecenal with the highest abundance and FD factor (16,384 and 4,096 by the solvent extraction and hot water extraction methods, respectively), plays an important role in the aroma quality of long coriander. These findings explain the similarities with the odor profiles of long coriander leaf extracts regardless of the extraction methods.

In the case of the hot water extraction method, the quantity of the aldehyde group that is expressed by the absolute content was over one-tenth compared to that obtained by the solvent extraction method. Meanwhile, both the alcohol and acid contents increased by approximately 3 times compared to those obtained by the solvent extraction method. While the content of the other alcohols seemed to remain constant between the two extraction methods, (Z)-3-hexenol and (E)-2-dodecenol were newly identified. In the current experiment, although the formation of (Z)-3-hexenol was not fully understood, it may be inferred that (E)-2-dodecenol was formed by its corresponding aldehyde. In addition, the corresponding acid was also formed from the aldehyde via oxidation reaction. It is thought that the essential aldehyde content decreased due to the conversion to alcohol and acid when the hot water extraction method was applied.

Based on these results, it can be presumed that aldehyde reductase and aldehyde dehydrogenase exist in the herb, similar to the enzymatic activity in two other members of cilantro mimics, and influence the herb’s odor quality. To confirm the observation, enzyme assays were conducted with the crude enzyme isolated from acetone powder of fresh Japanese long coriander leaves.

**Enzyme activities and its relation to the odor compounds** The enzyme activity of aliphatic aldehyde reductase was examined by incubating the crude enzyme solution isolated from acetone powder prepared from fresh herb. The two different buffer systems of Na-phosphate (pH range from 5.0 to 7.0) and glycine-NaOH (pH range from 8.0 to 10.0) with the addition of NADH/NADPH as a coenzyme using heptanal as a substrate were used. The enzyme activity was assayed by recording the decrease in heptanal and the corresponding increase in heptanol on GC.

When the pH was changed from 5 to 10 by the addition of NADPH to the reaction mixture, the long coriander enzyme was strongly activated in an alkaline condition with the maximum activity observed at pH 8.0. However, when NADH was added to the reaction mixture, a weaker activity of the enzyme was observed in a wider pH range (Fig. 2).

Additionally, to investigate the substrate specificity, the crude enzyme from fresh leaves and NADH/NADPH was

![Fig. 2. Effect of pH on the formations of heptanol and heptanoic acid from heptanal in the crude enzyme solution of Japnese long coriander leaves added with NADH/NADPH.](attachment:fig2.png)

The enzyme assay used heptanal as a substrate. The assay mixture (1 mL) contained 400 μL of 250 mM Na-phosphate (pH range from 5.0 to 7.0) or glycine-NaOH buffer (pH range from 8.0 to 10.0), 200 μL of MQ water, 100 μL of 10 mM NADH/NADPH, 250 μL of the crude enzyme, and 50 μL of 20 mM heptanal to initiate the reaction. The mixture was incubated at 37°C for 1 h. Each value is the mean of n = 2.
incubated with various aliphatic aldehydes (C6 to C12 saturated and C10, C12 and C14 unsaturated aldehydes), which were identified as the major components in the aroma concentrates extracted directly from the long coriander leaves as a substrate. As shown in Fig. 3, the enzyme revealed a broad substrate specificity and aliphatic aldehydes were found to be good substrates when added NADH or NADPH with varied rates of reduction significantly. One possible explanation is the high hydrophobicity of long chain aldehydes (carbon number is more than 10), followed by their low reactivity in the enzyme reaction mixtures, accompanied by weak affinity of the activated reductase for these aldehydes. The enzyme activity for C6 – C10 saturated aldehydes with the addition of NADPH was not significantly stronger than that with NADH, whereas in the case of undecanal, dodecanal, and (E)-2-decenal, the enzyme activity was more strongly activated with the addition of NADPH than with NADH as a coenzyme, leading to a larger amount of their corresponding alcohols formed. Moreover, when (E)-2-dodecenal or (E)-2-tetradecenal was used as a substrate with the addition of NADPH to the enzyme reaction, their corresponding alcohols were generated. However, the generation of the corresponding alcohol could not be significantly detected by GC analysis when NADH was added to the reaction, indicating that the enzymatic activities depended on the coenzyme used.

Inhibition of aliphatic aldehyde reductase was measured in the presence of p-hydroxymercurybenzoate. The crude enzyme from the long coriander leaves and NADH/NADPH were incubated for 2 min prior to adding heptanal as a substrate to test its inhibitory effect. Assays were conducted at 37°C and pH 8.0 for 1 h. The standard assay contained 400 μL of 250 mM buffer, MQ water, 100 μL of 10 mM NADH or NADPH, 250 μL of the crude enzyme solution, p-hydroxymercurybenzoate at varied concentrations, and 50 μL of 20 mM heptanal at a total volume of 1 mL in sealed reaction vials. As a result, aliphatic aldehyde reductase from the long coriander leaves was completely inhibited by p-hydroxymercurybenzoate, a strong inhibitor of aldose aldehyde reductase, as described previously (Negm, 1986), at a concentration of 5 mM when either NADH or NADPH was added. Although the formation of (E)-2-dodecenol occurred due to the endogenous aldehyde reductase in hot water extract, the enzyme has weak activities on the unsaturated aldehydes and thus, their corresponding alcohol was formed, but in small quantities (Table 1).

In addition to alcohol formation, as shown in Fig. 2, a small amount of heptanoic acid was detected in the reaction

![Fig. 3. Corresponding alcohols in the enzyme reaction mixtures generated from various aliphatic aldehydes. The enzyme assay was conducted at 37°C for 1 h, using aliphatic aldehyde as a substrate. The assay mixture (1 mL) contained 400 μL of 250 mM glycine-NaOH buffer (pH 8.0), 200 μL of MQ water, 100 μL of 2 mM NADH/ NADPH, 200 μL of the crude enzyme, and 100 μL of 2 mM of each aldehyde as a substrate to start the reaction. Each value is the mean of n = 2.](image-url)
mixtures of the aldehyde reductase assay. The acid formation was probably due to the presence of another enzyme activity related to the acid formation in the crude enzyme solution. Moreover, the aliphatic aldehyde dehydrogenase assay was conducted using heptanal as a substrate and NAD/NADP as a coenzyme. As a result, heptanoic acid was apparently formed in a wide range of pH, though the enzyme was found to have weaker activity compared to that of aldehyde reductase (Fig. 4). Besides the formation of a small amount of heptanoic acid, heptanol was also apparently formed in the reaction mixtures, suggesting the formation of NADH/NADPH from NAD/NADP as the products of the original enzymatic reaction. With the formation of NADH/NADPH as a new coenzyme in the reaction mixture, a part of heptanal was transformed to heptanol by the action of aliphatic aldehyde dehydrogenase that already existed in the crude enzyme.

The reverse reaction, i.e., hydrogenation of acids to their corresponding aldehydes, was also assayed with heptanoic acid as a substrate. No significant activity was detected under the experimental condition when either NADH or NADPH was added.

In conclusion, the enzymatic activity identified in the long coriander herb showed similarities with the enzymes detected in coriander and Vietnamese coriander leaves. In the crude enzyme solution, the aliphatic aldehyde reductase of long coriander was found to be less effective on aliphatic aldehydes than the aliphatic aldehyde reductase of coriander (data not shown). However, the enzymes were activated to influence the odor composition of these herbs such as the decrease in aldehyde content, increase in acid quantity, and formation of the alcohol group, explaining the poorer fresh green note in the hot water extraction sample compared to the fresh leaves in the sensory evaluation (Fig. 1).

Although much research has been reported on the odor of long coriander, the overall view of aroma characteristics as well as enzymatic activities of Japanese long coriander were clarified for the first time in the current study.

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References


