Purification and Biochemical Characterization of Cysteine Protease from Baby Kiwi (*Actinidia arguta*)

Sayaka Miyazaki-Katamura\(^1,2\), Mio Yoneta-Wada\(^1,3\), Miyuki Kozuka\(^4,3\), Tomohisa Sakaue\(^6\), Takuya Yamane\(^5,3\), Junko Suzuki\(^1\), Yoshihito Arakawa\(^1,3\) and Iwao Ohkubo\(^1,8,*\)

\(^1\)Department of Nutrition, School of Nursing and Nutrition, Tenshi College, Sapporo 065-0013, Japan  
\(^2\)Department of Food Science and Human Wellness, College of Agriculture, Food and Environmental Sciences, Rakuno Gakuen University, Ebetsu 069-0836, Japan  
\(^3\)Department of Nutrition, School of Nursing and Nutrition, Sapporo University of Health Sciences, Sapporo 061-1449, Japan  
\(^4\)Department of Health and Nutrition, Faculty of Human Science, Hokkaido Bunkyo University, Eniwa 061-0812, Japan  
\(^5\)Graduate School of Pharmaceutical Sciences, Hokkaido University, Sapporo 060-0812, Japan  
\(^6\)Department of Biochemistry and Molecular Genetics, Ehime University Graduate School of Medicine, Toon 791-0295, Japan  
\(^7\)Center for Research and Development Bioresources, Research Organization for University-Community Collaborations, Osaka Prefecture University, Sakai 599-8570, Japan  
\(^8\)Department of Pediatrics, Mikasa City Hospital, Mikasa 068-2156, Japan

Abstract:

Background: It has recently been reported that the fruit, stems and leaves of *Actinidia arguta* have various potential health effects including an antioxidant effect, anticancer effect, anti-allergic effect and α-glucosidase inhibitory effect. However, little is known about the biochemical properties of cysteine protease in the fruit juice of *A. arguta*.

Methods: Ion exchange chromatography to purify the cysteine protease from the fruit juice of *A. arguta*, and some synthetic substrates to determine the enzyme activity were used.

Results: Cysteine protease was purified to homogeneity from *A. arguta* fruit juice by ion exchange chromatography. The molecular weight of the purified enzyme was calculated to be approximately 25,500 by SDS-PAGE in the presence of β-ME. The enzyme rapidly hydrolyzed the substrate Z-Leu-Arg-MCA and moderately hydrolyzed other substrates including Boc-Val-Leu-Lys-MCA, Z-Val-Val-Arg-MCA and Z-Phe-Arg-MCA. Kinetic parameters for these four substrates were determined. The *K*\(_m\), *V*\(_{max}\), *K*\(_{cat}\) and *K*\(_{cat}\)/*K*\(_m\) values for Z-Leu-Arg-MCA, the most preferentially cleaved by the enzyme, were 100 μM, 63.8 μmoles/mg/min, 27.26 sec\(^{-1}\) and 0.2726 sec\(^{-1}\)μM\(^{-1}\), respectively. Furthermore, the activity of the enzyme was strongly inhibited by inhibitors including antipain, leupeptin, E-64, E-64c, kinin-free-LMW kininogen and cystatin C. Those biochemical data indicated that the enzyme was a cysteine protease. The amino acid sequence of the first 21 residues of cysteine protease purified from *Actinidia arguta* was Val\(^1\)-Leu-Pro-Asp-Tyr\(^2\)-Val-Asp-Trp-Arg-Ser\(^5\)-Ala-Gly-Ala-Val-Val\(^9\)-Asp-Ile-Lys-Ser-Qln\(^20\)-Gly. This sequence showed high homology to the sequences of actinidin from *Actinidia deliciosa* (95.0%) and actinidin from *Actinidia eriantha* (90%). These three cysteine proteases were thought to be common allied species.

Conclusion: The biochemical properties of the enzyme purified from *A. arguta* fruit juice were determined. These basic data are expected to contribute to the maintenance and improvement of human health as well as to the promotion of protein digestion and absorption through its proteolytic functions.

Keywords: *Actinidia arguta*, Cysteine protease, Purification, Biochemical properties, Allied species, Chromatography.

Article History

Received: April 30, 2019  
Revised: July 31, 2019  
Accepted: August 02, 2019

DOI: 10.2174/1874091X01913010054, 2019, J3, 54-63
1. INTRODUCTION

_Acclinidia arguta_ Planch., known as baby kiwi, hardy kiwi or arctic kiwi in English and Sarunashi in Japanese, is a vine tree that is natively widespread in Northern Asia including Russian Siberia, Northern China, Korea, Japan [1] and also in southern Asia including Vietnam, Peninsular Malaysia and New Guinea [2].

_A. arguta_ is an edible small fruit-producing perennial vine belonging to the _Actinidia_ genus in the _Actinidiaceae_ family and produces a small fruit that is rich in anthocyanins, catechins, chlorophyll, β-carotene, vitamin C, lutein, several minerals (potassium, calcium and zinc) and other polyphenols [3].

It has recently been reported that the fruit, stems and leaves of _A. arguta_ have various potential health effects including an antioxidant effect [4 - 6], antiproliferative effect [4], anticancer property [7], antimitogenesis effect [8], anti-allergic effect [9] and α-glucosidase inhibitory effect [9, 10]. Thus, the properties of _A. arguta_ are thought to be beneficial for human health.

Furthermore, the proteolytic properties of actinidin, bromelain, ficin and papain, which have been identified in kiwifruit [11, 12], pineapple [13], figs [14] and papaya [15], have been extensively studied as good meat tenderizers [12 - 16]. All of these proteases have been confirmed to be cysteine proteases [EC 3.4.22.-]. They are categorized into clan CA and family C1 (papain family) (see Merops: http://www.merops.ac.uk).

The cDNA structure and amino acid sequence derived from cDNA structures of cysteine protease from _A. arguta_ have been reported [17], and the crystallographical structure of the enzyme has also been determined [18]. However, little is known about the biochemical and physiological properties of cysteine protease in the fruit juice of _A. arguta_ [19].

In this paper, we describe a simple procedure for the isolation of cysteine protease from baby kiwi ( _A. arguta_ ) fruit juice and we also report the biochemical and physiological properties including molecular weight, kinetic parameters and N-terminal amino acid sequence.

2. MATERIALS AND METHODS

2.1. Materials

Frozen fruit samples of baby kiwi ( _A. arguta_ ) harvested in the vicinity of Sapporo City (Hokkaido, Japan) that had been ripened for 2 days at room temperature were stored at -30°C until use.

Silver vine ( _Actinidia polygama_ ) was also harvested in the vicinity of Kushiro City (Hokkaido, Japan), and both green kiwi ( _Actinidia delicosa_ cv. Hayward) and gold kiwi ( _Actinidia chinensis_ cv. Hort16A) fruits were purchased from a city market.

Protease inhibitors including E-64, and antipain and fluoro-
Step 2. UNO sphere Q Column Chromatography

The dialysate was applied at a flow rate of 1.0 ml/min to a UNOsphere Q column (bed volume, 20 ml) pre-equilibrated with 20 mM Tris-HCl buffer, pH 8.0, containing 10 mM β-ME. The column was washed extensively with the same equilibration buffer, and then a linear gradient was formed with 100 ml of the same buffer and 100 ml of the same buffer containing 0.45 M NaCl. Fractions containing cysteine protease activity were collected. The solution was immediately used in subsequent experiments.

2.6.1. Kinetic Analysis

The concentration of an inhibitor that gave 50% inhibition (IC₅₀) was determined through a series of assays with a fixed substrate concentration of 100 μM but with various inhibitor concentrations.

To determine Km and Vmax values, double-reciprocal plots (Lineweaver-Burk plots) were utilized.

2.6.2. N-Terminal Amino Acid Sequencing

Purified cysteine protease (~ 20 μg; ~ 0.77 pmol) was subjected to electrophoresis in 15% SDS-PAGE and transferred to a polyvinylidene difluoride (PVDF) membrane (Bio-Rad Laboratories). The membrane was stained with 0.1% Coomassie Brilliant Blue R-250 in 10% methanol-7% acetic acid. The protein band to be examined was cut out, washed with 50% methanol, and then sequenced by automated Edman degradation using an Applied Biosystems Model 492 cLC (ABI, Foster City, CA, USA). A protein sequencer equipped with an online phenylthiohydantoin analyzer (ABI 120A analyzer, Foster City, CA, USA) was used.

3. RESULTS AND DISCUSSION

3.1. Activation of Cysteine Protease by β-ME

The enzyme from A. arguta fruit juice in the absence of β-ME showed very low activity using the substrate Z-Leu-Arg-MCA. However, in the presence of 5~15 mM β-ME, the enzyme showed about 160~220-fold higher activity than the activity in the absence of β-ME (Fig. 1). These results indicated that the enzyme exists as a precursor form in the fruit juice and that the enzyme is activated by sulfhydryl reagents such as β-ME and cysteine [22, 23]. Accordingly, 10 mM β-ME was added to the assay mixture and purification buffer (Tris-HCl buffer, pH 8.0) in subsequent experiments.

![Graph](Image)  
**Fig. (1).** Activation of cysteine protease by β-ME.  
Each value is the mean ± SE from triplicate experiments.
3.2. Comparison of Specific Activities Among A. arguta, A. deliciosa, A. chinensis and A. polygama
The enzyme activities of fruit juices extracted from A. arguta, A. deliciosa, A. chinensis and A. polygama were determined in the presence of 10 mM β-ME using the substrate Z-Leu-Arg-MCA. The activity of A. arguta fruit juice showed the highest activity (Table 1). The order of their relative activities was A. arguta (16.97 μmoles/mg/min, 100%) > A. deliciosa (7.70 μmoles/mg/min, 45.4%) > A. polygama (0.83 μmoles/mg/min, 4.89%) > A. chinensis (0.025 μmoles/mg/min, 0.0015%).

3.3. Enzyme Purification
Cysteine protease from A. arguta was purified by chromatography on a UNOsphere Q column (Fig. 2). Table 2 shows a typical procedure for purification of the enzyme. Finally, the cysteine protease from A. arguta was purified approximately 2.12-fold with a 62.1% yield over dialyzed A. arguta homogenate. The enzyme in the final step gave a single band on SDS-PAGE in the presence of β-ME (Fig. 2). The overall yield of cysteine protease from 100 g of A. arguta was approximately 13.3 mg.

Table 1. Comparison of specific activities among A. arguta, A. deliciosa, A. chinensis and A. polygama.

<table>
<thead>
<tr>
<th></th>
<th>Specific Activity (μmoles/mg/min)</th>
<th>Relative Activity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actinidia arguta</td>
<td>16.97</td>
<td>100.0</td>
</tr>
<tr>
<td>Actinidia deliciosa</td>
<td>7.70</td>
<td>45.4</td>
</tr>
<tr>
<td>Actinidia chinensis</td>
<td>0.025</td>
<td>0.015</td>
</tr>
<tr>
<td>Actinidia polygama</td>
<td>0.83</td>
<td>4.89</td>
</tr>
</tbody>
</table>

Table 2. Purification of cysteine protease from A. arguta.

<table>
<thead>
<tr>
<th>Step</th>
<th>Total Protein (mg)</th>
<th>Total Activity (units)</th>
<th>Specific Activity (μmoles/mg/min)</th>
<th>Purification (-fold)</th>
<th>Yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dialysis</td>
<td>70.35</td>
<td>1980</td>
<td>28.15</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>UNOsphere Q</td>
<td>20.59</td>
<td>1228.8</td>
<td>59.68</td>
<td>2.12</td>
<td>62.1</td>
</tr>
</tbody>
</table>

*Protein concentration was measured by Bradford’s method using bovine serum albumin as a standard.

Fig. (2). Purification of cysteine protease from Actinidia arguta using UNOsphere Q column chromatography. Fractions containing cysteine protease activity were collected. The bar indicates the fractions that were pooled. Protein concentration (mg/ml) (○), cysteine protease activity (■) and sodium chloride gradient (−). Insert: SDS-PAGE of fractions containing the enzyme activity. 3 μl of each aliquot (fraction numbers 37 to 45) was subjected to SDS-PAGE.
3.4. Biochemical Properties of the Purified Enzyme

3.4.1. Molecular Weight

Cysteine protease from *A. arguta* fruit juice was purified to homogeneity, and the molecular weight of the enzyme was calculated to be approximately 25,500 on SDS-PAGE (Fig. 3). The value of its molecular weight was close to those of enzymes from other plants including actinidin (Mr 23,000 ~ 24,000) [18, 24, 25], papain (Mr 23,400) [26] and ficain (ficin) (Mr 23,400) [27].

![Fig. (3). Polyacrylamide gel electrophoresis of cysteine protease from *Actinidia arguta*. Electrophoresis of the purified enzyme was carried out on a Mini-protean TGX precast gel (any kDa) in the presence of SDS and the gel was stained with Coomassie Brilliant Blue G-250. Lane 1 contained 5 μg of the purified protein in the presence of β-ME. Precision Plus protein standards (Bio-Rad) were also used for estimation of molecular weight.](image)

3.4.2. Substrate Specificity

As shown in Fig. (4), cysteine protease from *Actinidia arguta* exhibited high activity toward the synthetic substrate Z-Leu-Arg-MCA and moderate activity toward Z-Val-Leu-Lys-MCA, Z-Val-Val-Arg-MCA, Z-Phe-Arg-MCA and Pro-Phe-Arg-MCA. Furthermore, the enzyme very weakly hydrolyzed the substrates Z-Gly-Pro-Arg-MCA, Boc-Val-Pro-Arg-MCA and Z-Arg-Arg-MCA. It did not hydrolyze substrates for cathepsin H (Arg-MCA), elastase (Suc-Ala-Ala-Ala-MCA) and tripeptidyl peptidase II (Ala-Ala-Phe-MCA).

Our results indicated that the enzyme preferentially cleaves the peptide bond between P<sup>1</sup> (Arg or Lys) and P<sup>′</sup> positions in the presence of a hydrophobic amino acid such as Leu, Val and Phe at the P<sup>2</sup> position.

3.4.3. Optimal pH, pH Stability, Optimal Temperature and Thermo-stability

Cysteine protease activity was assayed in the pH range of 3.0 to 8.0 using citrate and sodium-phosphate buffers. The activity of cysteine protease toward the substrate Z-Leu-Arg-MCA was optimal at pH 6.5 - 7.5 when sodium phosphate buffer was used (Fig. 5A).

To examine the effect of pH on stability, the enzyme was incubated at various pH values (GTA buffer: 3.5 to 10.0) for 24 hr at 4°C. The enzyme was stable over a wide pH range from 4.0 to 8.5 (Fig. 5B).

The temperature for the optimal hydrolysis of the above substrate was approximately 50°C (Fig. 5C).

The enzyme activity was thermo-stable up to 45°C for 10 min of incubation (Fig. 5D).

In 20 mM sodium phosphate buffer, pH 7.0, the enzyme was stable for at least 7 days at 4°C and three months at -30°C.

3.4.4. Kinetic Parameters

The *K<sub>m</sub>*, *V<sub>max</sub>* , *K<sub>cat</sub>* and *K<sub>cat</sub>/K<sub>m</sub>* values of the purified enzyme for four substrates at optimal pH (pH 7.0) were determined (Table 2). The *K<sub>m</sub>* , *V<sub>max</sub>* , *K<sub>cat</sub>* and *K<sub>cat</sub>/K<sub>m</sub>* values for Z-Leu-Arg-MCA, which was most preferentially cleaved by the enzyme, were 100 μM, 63.8 μmoles/mg/min, 27.12 sec<sup>-1</sup> and 0.2712 sec<sup>-1</sup> μM<sup>-1</sup>, respectively. The relative order of *K<sub>cat</sub>* was Z-Leu-Arg-MCA > Boc-Val-Leu-Lys-MCA ≥ Z-Val-Val-Arg-MCA > Z-Phe-Arg-MCA and the relative order of *K<sub>cat</sub>/K<sub>m</sub>* was Z-Leu-Arg-MCA > Boc-Val-Leu-Lys-MCA ≥ Z-Val-Val-Arg-MCA > Z-Phe-Arg-MCA. These results indicated that Z-Leu-Arg-MCA is the best substrate among the four substrates and coincided with the results shown in Fig. (4).

3.4.5. Inhibition of Enzyme Activity by Standard Protease Inhibitors

Various protease inhibitors against cysteine protease from *A. arguta* were examined (Fig. 6). Cysteine protease activity was strongly inhibited by antipain, leupeptin, E-64 and E-64c, and Z-LLL-H (aldehyde) and was moderately inhibited by pepstatin A. However, the enzyme activity was not inhibited by EDTA, AEBSF, CA-074 and leuhistin. Accordingly, the enzyme from *A. arguta* was confirmed to belong to the cysteine protease family.
Fig. (4). Substrate specificity of purified cysteine protease from *Actinidia arguta*. Each assay was carried out at 37°C for 10 min in 50 mM sodium phosphate buffer, pH 7.0, in the presence of the purified enzyme (0.5 μg) and 100 μM of a substrate. Each value is the mean ± SE from triplicate experiments.

Fig. (5). Optimal pH, pH stability, optimal temperature and heat-stability of purified cysteine protease from *Actinidia arguta*. (A): The purified enzyme (0.5 μg) was incubated in 50 mM citrate buffer and sodium phosphate buffer at various pHs (3.0 ~ 8.0) for 10 min at 37 °C. The activity for Z-Leu-Arg-MCA was determined, and the activity obtained at pH 7.0 was used as the standard (100%). Each value is the mean ± SE from triplicate experiments. (○): sodium phosphate buffer; (□): sodium citrate buffer. (B): The purified enzyme (0.5 μg) was stored in 50 mM...
GTA buffer at various pHs (3.5 – 10.0) for 24 hr at 4°C, and then the activity for Z-Leu-Arg-MCA was determined. The activity obtained at pH 7.0 was used as the standard (100%). Each value is the mean ± SE from triplicate experiments. (C): The purified enzyme (0.5 μg) was incubated in 50 mM sodium phosphate buffer, pH 7.0, at various temperatures (22 – 60°C) for 10 min. The activity for Z-Leu-Arg-MCA was determined, and the activity obtained at 37 °C was used as the standard (100%). Each value is the mean ± SE from triplicate experiments. (D): The purified enzyme (0.5 μg) was pre-incubated in 50 mM sodium phosphate buffer, pH 7.0, at various temperatures (22 – 60°C) for 10 min and then incubated for an additional 10 min after an addition of the substrate. The activity obtained at 22°C was used as the standard (100%). Each value is the mean ± SE from triplicate experiments.

Table 3. Kinetic parameters of cysteine protease from *A. arguta* toward several substrates.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>( \text{K}_m ) (μM)</th>
<th>( \text{V}_{\text{max}} ) (μmoles/mg/min)</th>
<th>( \text{K}_{\text{cat}} ) (sec(^{-1}))</th>
<th>( \text{K}_{\text{cat}}/\text{K}_m ) (sec(^{-1})μM(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z-Leu-Arg-MCA</td>
<td>100</td>
<td>63.8</td>
<td>27.26</td>
<td>0.2726</td>
</tr>
<tr>
<td>Z-Val-Val-Arg-MCA</td>
<td>263</td>
<td>41.4</td>
<td>17.69</td>
<td>0.0672</td>
</tr>
<tr>
<td>Boc-Val-Leu-Lys-MCA</td>
<td>91</td>
<td>41.5</td>
<td>17.74</td>
<td>0.1949</td>
</tr>
<tr>
<td>Z-Phe-Arg-MCA</td>
<td>222</td>
<td>34.9</td>
<td>14.91</td>
<td>0.0671</td>
</tr>
</tbody>
</table>

Table 4. \( IC_{50} \) values of inhibitory activity of various inhibitors toward cysteine protease purified from *A. arguta*.

<table>
<thead>
<tr>
<th>Inhibitor</th>
<th>( IC_{50} ) (nM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-64</td>
<td>4.5</td>
</tr>
<tr>
<td>E-64c</td>
<td>11.5</td>
</tr>
<tr>
<td>CA-074</td>
<td>26,500.0</td>
</tr>
<tr>
<td>Leupeptin</td>
<td>55.0</td>
</tr>
<tr>
<td>Antipain</td>
<td>93.0</td>
</tr>
</tbody>
</table>
Table (4) contd....

<table>
<thead>
<tr>
<th>Inhibitor</th>
<th>IC&lt;sub&gt;50&lt;/sub&gt; (nM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z-LLL-H</td>
<td>9.0</td>
</tr>
<tr>
<td>Pepstatin A</td>
<td>160.0</td>
</tr>
<tr>
<td>Kinin-free LMW kininogen</td>
<td>4.6</td>
</tr>
<tr>
<td>Cystatin C</td>
<td>30.5</td>
</tr>
</tbody>
</table>

**Actinidia arguta**

VLPSY VDWRG AGAVV DIKSQ G 100.0%

**Actinidia deliciosa**

LSFY VDWRG AGAVV DIKSQ G 95.0%

**Actinidia eriantha**

LPDY VDWRG AGAVV VIKNQ G 90.0%

**Carica papaya**

LPDY VDWRG EGAVV PVKNQ G 60.0%

**Ananas comosus (Fruit)**

VPQS IDWRD YGAVT SVKNQ N 45.0%

**Ananas comosus (Stem)**

VPQS IDWRD YGAVT SVKNQ N 45.0%

Fig. (7). Comparison of the N-terminal amino acid sequence of cysteine protease from *Actinidia arguta* with those of cysteine proteases from *Actinidia delicosa*, *Actinidia eriantha*, *Carica papaya* and *Ananas comosus* (fruit and stem). The N-terminal amino acid sequence of cysteine protease from *Actinidia arguta* is aligned against the sequences of cysteine proteases from *Actinidia delicosa* (GenBank accession no. ABQ1090), *Actinidia eriantha* (ABQ 10191), *Carica Papaya* (AAB 02650) and *Ananas comosus* (fruit (BAA 21929) and stem (CA4 08360.1)). Non-conserved amino acid residues among the cysteine proteases of those fruits are shown in filled boxes.

The 50% inhibition (IC<sub>50</sub>) values of inhibitory activity of various inhibitors toward cysteine protease purified from *A. arguta* were determined with a fixed substrate concentration of 100 μM but with various inhibitor concentrations (Table 3).

The relative order of IC<sub>50</sub> values of synthetic inhibitors was E-64 > Z-LLL-H > E64c > leupetin > antipain. Furthermore, two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30]. LMW kininogen is well known to have two proteinase inhibitors, kinin-free LMW (low molecular weight) kininogen [28] and cystatin C [29], strongly inhibited the activity of the enzyme (IC<sub>50</sub> = 3.9 and 32.0 nM, respectively) [30].

The primary function of endogenous cysteine proteases in plants is thought to be protection against arthropod pests, plant-parasitic nematodes and herbivorous insects invading the plants [35, 36]. Endogenous cysteine proteases are also thought to be involved in many physiologically important processes such as disease resistance, programmed cell death, germination and senescence [37 - 41].

On the other hand, cysteine proteases such as papain, bromelin, ficin, actinidin and zingibain from some fruits have been extensively and effectively utilized for production of tender meat [12 - 16, 19, 42, 43], although their characteristics including optimal pH, optimal temperature and enzymatic kinetics for the production of tender meat have not been determined.

Montoya et al. [44, 45] reported that dietary actinidin from kiwifruit (*A. delicosa* cv. Hayward) increased gastric digestion and gastric emptying rate of several dietary proteins in growing rats [44] and meat proteins in growing pigs [45]. Accordingly, cysteine protease from *A. arguta* fruit juice is also expected to have the same nutritional effects.

On the other hand, Cavic et al. [46] and Grozdanovic et al. [47] reported that active actinidin is resistant to Simulated Gastric Fluid (SGF) and Simulated Intestinal Fluid (SIF) and can influence/increase the uptake of complete actinidin molecules and other barely degraded proteins by breaking down occludin (a key epithelial tight junction transmembrane protein) in the tight junction network. These findings indicate that food allergens with intrinsic proteolytic activity can endanger the gut epithelial barrier, thus contributing to the sensitization process in food allergy pathogenesis.

Functional and processed foods that utilize the distinctive feature of cysteine protease from *A. arguta* fruit juice to promote protein digestion and absorption should be developed.
and foods such as Actinidia arguta and kiwifruit (Actinidia deliciosa cv. Hayward) are also expected to contribute to the maintenance and improvement of human health through their proteolytic functions.

LIST OF ABBREVIATIONS

AEBSF = 4-(2-aminoethyl)-benzenesulfonyl fluoride
AMC = 7-amino-4-methylcoumarin
Boc = t-butyloxycarbonyl-
β-ME = β-mercaptoethanol
E-64 = N-[L-(3-trans-carboxyan-2-carbonyl)-L-leucyl]-agmatine
EDTA = ethylenediaminetetraacetic acid
LMW = low molecular weight
MCA = 4-methylcoumaryl-7-amide
PAGE = polyacrylamide gel electrophoresis
PMSF = phenylmethylsulfonyl fluoride
Z- = benzoyloxy-carbonyl-
SDS = sodium dodecyl sulfate

ETHICAL APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

HUMAN AND ANIMAL RIGHTS

No animals/humans were used for studies that are the basis of this research.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

FUNDING

This work was supported in part by grants from the Tenshi College Research Foundation (to I. Ohkubo).

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

Declared none.

REFERENCES

[21] Laemmli, U.K. Cleavage of structural proteins during the assembly of
Purification and Biochemical Characterization

The Open Biochemistry Journal, 2019, Volume 13


