Inhibitory Effect of Acteoside Isolated from Cistanche tubulosa on Chemical Mediator Release and Inflammatory Cytokine Production by RBL-2H3 and KU812 Cells

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Original Paper

Inhibitory effect of acteoside isolated from *Cistanche tubulosa* on chemical mediator release and inflammatory cytokine production by RBL-2H3 and KU812 cells

Parida Yamada[1], Rieko Iijima[2], Junkyu Han[1,2], Hideyuki Shigemori[2], Shinichi Yokota[3], Hiroko Isoda[1,2*]

[1] Alliance for Research on North Africa (ARENA), University of Tsukuba, Tsukuba, Japan

[2] Graduate School of Life and Environmental Sciences, University of Tsukuba, Tsukuba, Japan

[3] Frontier Biochemical & Medical Research Laboratories, Corporate Research & Development Division, KANEKA Corporation, Takasago, Japan

[*] **Address Correspondence**

Univ. Tsukuba-Prof. Dr. Hiroko Isoda

Graduate School of Life and Environmental Sciences

University of Tsukuba

1-1-1 Tennodai, Tsukuba, Ibaraki 305-8572 Japan

Tel: +81 29 853 5775

Fax: +81 29 853 5776

E-mail: isoda@sakura.cc.tsukuba.ac.jp

Parida Yamada and Rieko Iijima contributed equally to the paper.

Abstract

The immediate-type allergic reaction is involved in many allergic diseases such as asthma, allergic rhinitis and sinusitis. In this study, we investigated the effect of acteoside extracted from *Cistanche tubulosa* (Schrenk) R. Wight on the basophilic cell-mediated allergic reaction. The effect of acteoside on β-hexosaminidase release and intracellular $[Ca^{2+}]i$ level from rat basophilic leukemia (RBL-2H3) cells was determined. Also, ELISA was used to determine the level of histamine, tumor necrosis factor (TNF)-α and interleukin (IL)-4 on human basophilic (KU812) cells. The effect of acteoside on basophilic cell viability was determined using the 3-[4,5-dimethylthiazolyl]-2,5-diphenyltetrazolium bromide (MTT) assay. These results indicated that 0.1–10.0 μg/mL acteoside inhibit the release of β-hexosaminidase and $[Ca^{2+}]i$ influx from IgE-mediated RBL-2H3 cells. Also acteoside inhibited histamine release, TNF-α and IL-4 production in a dose-dependent manner from calcium ionophore A23187 plus phorbol 12-myristate 13-acetate (PMA) or compound 48/80-stimulated KU812 cells. Our findings provide evidence that acteoside inhibits basophilic cell-derived immediate-type and layed-type allergic reactions. This is the first report describing anti-allergic activity of acteoside extracted from *Cistanche tubulosa* on basophilic cells.

Key words

anti-allergic

acteoside

β-hexosaminidase

Cistanche tubulosa

cytokines

histamine

Orobanchaceae

Abbreviations:

IL-4:	interleukin-4
KU812:	human basophilic cells
MTT:	3-[4,5-dimethylthiazolyl]-2,5-diphenyltetrazolium bromide
PKC:	protein kinase C
PMA:	phorbol 12-myristate 13-acetate
RBL-2H3:	rat basophilic leukemia cells
TNF-α:	tumor necrosis factor-α

Introduction

Herba Cistanchis is the whole herb of Orobanchaceae family, Cistanche genus, other names such as Da Yun, Cong Rong, Cun Rong also exist. The herbs of the same genus named *Cistanche tubulosa* (Schrenk) R. Wight (Orobanchaceae) is a perennial parasitic plant growing on the roots of Salvadora or Calotropis species, and distributed in North Africa, Arabia and Asian countries. It has been traditionally used as a blood circulation-promoting agent and in the treatment of impotence, sterility, lumbago, body weakness and tonic [1-2]. *Cistanche tubulosa* extract has been shown to have effect on various brain diseases, anti-aging functions, metabolism of fat, and hair growth [3-6]. Recently, several compounds including iridoids, monoterponenoids, phenylethanoid glycosides such as acteoside, echinacoside and cistanoside A, and lignans were isolated from Chinese and Pakistan *Cistanche tubulosa* [1, 7]. Some of these phenylethanoid glycosides appear to have various biological activities, such as anti-inflammatory anti-oxidant, and relaxation properties [8-10]. Moreover, acteoside extracted from *Cistanche tubulosa* regulated immunity on aging mice [11], also acteoside isolated from *Clerodendron trichotomum thunberg* have anti-inflammatory effect on melittin-stimulated RBL-2H3 cells [12], and lipopolysaccharide-stimulated mouse peritoneal macrophage [13]. Considerable data on the acteoside and echinacoside extracted from *Cistanche tubulosa* have been reported with the few studies on antioxidant effect. However, their anti-allergic effects have not been studied.

Type I allergy is induced by certain types of antigens such as foods, dust mites, medicines, pollen, and cosmetics. This type of antigens induces production of antigen-specific IgE antibodies that bind to receptors on mast cells or basophilic cells. Recently, the early phase and late phase reactions, have been reported in type I allergy. The early phase reaction in

type I allergy occurs within a few minutes and then mediators such as histamine and serotonin are released from the cell. The late phase reaction occurs hours after the early phase reaction in type I allergy, the mediators such as inflammatory cytokines TNF-α, IL-4, IL-6, IL-8, and IL-13 are secreted from the cells, respectively [14-16]. β-Hexosaminidase, which is stored in the secretiory granules of mast cells is released concomitantly with histamine when mast cells are immunologically activated. Thus, β-hexosaminidase activity in the medium is used as a marker of mast cell degranulation [17-18]. RBL-2H3 cells have been extensively used for studying IgE–FcεRI (the high affinity IgE receptor) interactions [19], signaling pathways for degranulation [20], and gene expression of inflammatory cytokines [21]. RBL-2H3 cells are therefore considered as a good tool for studying the effect of unknown compounds on histamine release or β-hexosaminidase release activity.

Basophils and mast cells types originate from the hematopoietic stem cells and share several biochemical and functional properties. Human mast cells are useful cells for studying synthesis of mediators and cytokine activation pathway because they secrete histamine and many inflammatory cytokines, when stimulated with phorbol esters and calcium ionophore A23187 [22-23]. Both basophils and mast cells play a major role in the pathogenesis of inflammatory diseases by releasing several pro-inflammatory mediators [24]. Activated mast cells can produce histamine, as well as wide variety of other inflammatory mediators such as eicosanoids, proteoglycans, proteases and several proinflammatory and chemotactic cytokines such as TNF-α, IL-6, IL-4, IL-8, and IL-13. Therefore, modulation of secretion of these cytokines from mast cells can provide a useful therapeutic strategy for allergic inflammatory disease [23, 25].

In this study, we investigated inhibition effect of three phenylethanoid glycosides derived from *Cistanche tubulosa* on β-hexosaminidase release by IgE-mediated RBL-2H3 cells as

type I allergy model, and inhibition effect of acteoside on histamine release from A23187 plus PMA or compound 48/80-stimulated KU812 cells, and on cytokines production by the same cell line.

Materials and methods

Cell lines, chemicals and biochemicals

RBL-2H3 cells were purchased from JCRB Cell Bank, Japan. The cells were maintained in MEM supplemented with 10%FBS and 2 mM L-glutamine, while KU812 cells were purchased from Riken Cell Bank, Japan. The cells were maintained in a RPMI 1640 medium supplemented with 10%FBS, and the cells incubated at 37^{o}C in a 5%CO_2 incubator. Dinitrophenylated bovine serum albumin (DNP-BSA) was purchased from Cosmo Biotechnology Co., Ltd. Anti-DNP-IgE, ketotifen fumarate salt (>99%), L-glutamine, calcium ionophore A23187, PMA and compound 48/80 were purchased from Sigma-Aldrich. Fetal bovine serum (FBS) was purchased from Hyclone Co., Ltd. Eagle's Minimum Essential Medium (MEM) was purchased from Nissui Pharmaceutical Co., Ltd. 3-[4,5-dimethylthiazolyl]-2,5-diphenyltetrazolium bromide (MTT) was purchased from Dojindo. Co., Ltd.

Plant material

The stems of *Cistanche tubulosa* (Orobanchaceae) were purchased from Shinwa Bussan Co., Ltd, in Osaka, Japan and identified by botany expert, and their voucher specimens (UT-CT040401) were deposited in the Graduate School of Life and Environmental Sciences, University of Tsukuba, Ibaraki, Japan.

Extraction and isolation

The stems of *Cistanche tubulosa* (500 g) were extracted with MeOH (1.5 l), and evaporated to dryness *in vacuo* at 30°C. The MeOH extract was partitioned between EtOAc (1.0 L × 3) and H_2O (1.0 L) and then the H_2O layer was partitioned with *n*-BuOH (1.0 L × 3). The *n*-BuOH-soluble portion (3.1 g) was subjected to a ODS column (Cosmosil ODS, 2.2 x 30 cm, MeOH/H_2O, 3:7→1:0) to separate twelve fractions (CT-BU-1~12) including echinacoside (CT-BU-9, 25.4 mg). CT-BU-10 (491 mg) was applied to a silica gel column (2.2 × 30 cm, $CHCl_3$/MeOH/H_2O, 80:25:3) to afford thirteen fractions (CT-BU-10-1~13) including cistanoside A (CT-BU-10-11, 86.2 mg), and using a silica gel column (2.2 × 30 cm, $CHCl_3$/MeOH/H_2O, 80:25:3) to obtain acteoside (12.1 mg) from CT-BU-10-9 fraction. The purity (>90%) of these three phenylethanoid glycosides, acteoside, echinacoside, and cistanoside A were determined by the high performance liquid chromatography (HPLC) and nuclear magnetic resonance (NMR) spectra. The three compounds were identified by comparisons of the ^{1}H and ^{13}C NMR data with those previously reported in the literatures. Chemical structures of three phenylethanoid glycosides extracted from *Cistanche tubulosa* are shown in **Fig. 1**.

MTT assay

The MTT assay is a sensitive and quantitative colorimetric assay that is used to determine cell viability [26]. RBL-2H3 cells and KU812 cells were harvested at approximately 60-80% confluence and seed onto 96-well plate at 5.0×10^4 cells/well in 100 µL medium. After an overnight incubation, the cells were washed twice with PBS (-) and 100 µL of medium with three phenylethanoid glycosides (0.1-100.0 µg/mL) was added. The cells were incubated for 48 h, before 10 µL of 5 mg/mL of MTT added. After 24 h of incubation, 180 µL of 10%

sodium dodecyl sulfate (SDS) was added, this being followed by another 24 h of incubation to completely dissolve the formazan produced by the cells. The absorbance was then determined at 570 nm with a microplate reader (Power Scan HT, Dainippon Pharmaceutical Co., Ltd.). Blanks were also prepared at the same treatment. The optical density of the formazan produced by the untreated control cells was considered as representing 100% viability.

β-Hexosaminidase release assay

The β-hexosaminidase release inhibition assay using RBL-2H3 cells was performed as previously described [26]. RBL-2H3 cells were seeded onto 96-well plates (Falcon Co.) at 5.0×10^4 cells/well in 100 μL of medium. The cells were incubated for 24 h at 37°C and sensitized with 0.3 μg/mL anti-DNP-IgE, then washed twice with PBS (-) to eliminate free IgE. After incubating the cells at 37°C for 10 min in 60 μL per well of a releasing mixture containing 5 μL of three phenylethanoid glycosides (0.1-10.0 μg/mL), the cells were exposed to 0.3 μg/mL DNP-BSA in PBS (-) followed by incubation at 37°C for 1 h. For positive and negative controls, 3 mM ketotifen fumarate salt (Keto.) and PBS (-) were used, respectively. Then, 80 μL of substrate solution was then added to 20 μL of the supernatant followed by incubation at 37°C for 30 min. After adding 100 μL/well of stop buffer, the absorbance at 405 nm was obtained using a microplate reader. The percentage of β-hexosaminidase released was calculated using the following equation:

$$\beta\text{-hexosaminidase release (\%)} = \{(T-B_t) / (C-B_c)\} \times 100$$

Control (C): Cell (+), DNP-BSA (+), test sample (-); Test (T): Cell (+), DNP-BSA (+), test sample (+); $Blank_t$ (B_t): Cell (-), DNP-BSA (+), test sample (+); $Blank_c$ (B_c): Cell (-), DNP-BSA (+), test sample (-).

Determination of intracellular [Ca^{2+}]*i* level

[Ca^{2+}]*i* measurement was performed by the method of Aase and Arna [27] with some modifications. RBL-2H3 cells (5.0×10^4 cells per well in 100 µL of medium) were precultured at 37°C for 24 h in 96-well plates using a medium containing 10%FBS and 0.3 µg/mL anti-DNP IgE. The cells were washed twice with 200 µL of PBS (-) to eliminate free IgE. The cells were then incubated with 100 µL per well of loading buffer containing Fluo3-AM (Calcium Kit-Fluo3, Dojindo Co., Ltd.) at 37°C for 1 h. The cells were then washed twice with 200 µL of PBS (-) to eliminate free Fluo3-AM, followed by incubation with 60 µL per well of recording medium at 37°C for 1 h in a 5%CO_2 incubator with of sample (0.1, 1.0, and 10.0 µg/mL acteoside). For positive and negative controls, 3 mM Keto. and PBS (-) were used, respectively. The fluorescence intensity (FI) was determined 150 sec after adding 0.3 µg/mL of DNP-BSA antigen. FI was measured at an excitation wavelength of 490 nm and emission wavelength of 530 nm using a microplate reader.

Histamine release assay

The histamine release inhibition assay using KU812 cells was performed as previously described [28] and according to the method described by Hosoda et al. [23] with some modifications. KU812 cells were suspended at 2.0×10^5 cells/well in 200 µL of Tyrode buffer A (30 mM Tris−HCl, 120 mM NaCl, 5 mM KCl, 1 mM $CaCl_2$, 1 mM $MgCl_2$, 5.6 mM glucose, and 0.03% BSA) for treatment with acteoside. The cells were next incubated with or without 25 µL/well of various concentrations of acteoside (0.1-10.0 µg/mL) for 15 min, and then stimulated with A23187 (1 µM) plus PMA (20 nM) or compound 48/80 (10 µg/mL) for 30 min at 37°C. The cells were separated from the released histamine by centrifugation

at 400 x g for 5 min at 4^{o}C. The supernatant (50 µL) was transferred to a 96-well ELISA system, and the histamine concentration was determined by ELISA kit according to the manufacturer's instructions. Histamine EIA kit (Oxford Biomedical Research, USA) were used to detect histamine content. The percentage of histamine released was calculated by using the following equation:

Histamine release (%) = {(T-N) / (C-N)} × 100

Control (C): A23187+PMA (+) or compound 48/80 (+), test sample (-); Test (T): A23187+PMA (+) or compound 48/80 (+), test sample (+); Normal (N): A23187+PAM (-) or compound 48/80 (-), test sample (-).

TNF-α and IL-4 production assay

The TNF-α and IL-4 production inhibition assay using KU812 cells was performed as previously described [28]. KU812 cells were seeded onto 96-well plates at 2.0 × 10^5 cells/well in 200 µL of medium, incubated with or without acteoside for 15 min and then stimulated with A23187 plus PMA for 16 h at 37^{o}C, 5%CO_2 incubator. The cells were separated from the secreted cytokine by centrifugation at 400 x g for 5 min at 4^{o}C. The supernatant (50 and 100 µL) was transferred to a 96-well ELISA system, and the TNF-α level and IL-4 concentration were determined by ELISA kit according to the manufacturer's instructions. Human TNF-α and IL-4 ELISA kit (Biosource International, USA) were used to detect TNF-α and IL-4, respectively. The absorbance at 450 nm was obtained using a microplate reader. To estimate the production of TNF-α or IL-4 by the cells, the same procedure was followed, but without the addition of A23187 plus PMA (Normal). Thus, the percentage of TNF-α or IL-4 production was calculated using the following equation.

Cytokine production (%) = {(T-N) / (C-N)} × 100

Control (C): A23187+PMA (+), test sample (-); Test (T): A23187+PMA (+), test sample (+); Normal (N): A23187+PMA (-), test sample (-).

Statistical analysis

Our results are expressed as means ± SD. The statistical evaluation of the results was performed by one-way analysis of variance (ANOVA) followed by Duncan's post hoc test.

Results

We used the MTT assay to assess the cytotoxicity of three phenylethanoid glycosides on RBL-2H3 cells and KU812 cells. The cells were treated with three phenylethanoid for 48 h at final concentration of 0.1-100.0 μg/mL. As show in **Fig. 2**, the tree phenylethanoid glycosides did not cause cytotoxicity at 0.1-10.0 μg/mL. But, the cell viability of the KU812 cells were decreased to 90% with the treatment of 100.0 μg/mL acteoside, and the effect being significant ($p < 0.01$, vs. the control value).

Three phenylethanoid glycosides were screened for their inhibitory effect on β-hexosaminidase release by RBL-2H3 cells. The β-hexosaminidase release from IgE-sensitized RBL-2H3 cells were induced by DNP-BSA as a stimulatory antigen. The β-hexosaminidase release from RBL-2H3 cells as affected by three phenylethanoid glycosides is shown in **Fig. 3**. Three phenylethanoid glycosides showed inhibitory effect on the β-hexosaminidase release, the effect being significant at all treatment of acteoside and 1.0-10.0 μg/mL treatment of cistanoside A ($p < 0.05$ and $p < 0.01$ vs. the BSA value). The echinacoside was shown inhibition effect at all treatment, but the effect was not significant compared with negative control (BSA). In the present study, we compared the effect of three phenylethanoid glycosides with the clinically available anti-allergic drug, Keto., which is known as a mast cell stabilizer, H1-receptor antagonist, eosinophil inhibitor [26]. Kim et al. [29] demonstrated that Keto. decrease β-hexosaminidase release and cytoplasm ROS level by IgE-mediated RBL-2H3 cells. The acteoside was the most potent among the three compounds at 1.0 μg/mL treatment, showing 29.9% inhibitory effect compared with 3 mM Keto. (final 214 μM, IC_{50}=200-300 μM) treatment (inhibition rate was 43.5%) (**Fig. 2**).

To examine the relationship between β-hexosaminidase release and $[Ca^{2+}]i$ levels in RBL-2H3

cells, we focusing on the acteoside which induced the highest inhibitory effect on β-hexosaminidase release, to determined the change in the $[Ca^{2+}]i$ levels. The increase rate of the $[Ca^{2+}]i$ level in IgE-mediated RBL-2H3 cells as affected by acteoside is shown in **Fig. 4**. Results reveal that after DNP-BSA stimulation, the cells showed a decrease in $[Ca^{2+}]i$ level at each acteoside treatment (**Fig. 4**). These result was suggest that acteoside suppressed $[Ca^{2+}]i$ influx in the IgE-sensitized BSA-stimulated RBL-2H3 cells. The reduction of $[Ca^{2+}]i$ levels with acteoside at 1.0-10.0 μg/mL treatment was higher than Keto. as positive control.

To investigate the inhibitory effect of acteoside on human basophilic cells, we examined A23187 plus PMA- or compound 48/ 80-induced KU812 cell activation. First of all, inhibitory effects of acteoside on A23187 plus PMA-induced KU812 cell degranulation were examined. Light microscopy photo showed that control KU812 cells generally are spherical or oval (**Fig. 5A**). After stimulation with A23187 plus PMA, the cell became swollen and had many vacuoles and extruded granules near the cell surface and in the surrounding medium, which is interpreted as mast cell degranulation (**Fig. 5B**). The cells became swollen with an irregular boundary, but the degranulation was reduced (**Figs. 5C** and **5D**) by preincubation with acteoside in the A23187 plus PMA stimulated KU812 cells.

The inhibitory effects of acteoside on A23187 plus PMA- or compound 48/80-mediated histamine release from KU812 cells are shown in **Fig. 6**. Acteoside dose-dependently inhibited A23187 plus PMA (**Fig. 6A**)- or compound 48/80 (**Fig. 6B**)-mediated histamine release in a concentration range of 0.1-10.0 μg/mL. The histamine release was inhibited approximately 63.2, 100.0, and 100.0% after treatment with the acteoside at 0.1-10.0 μg/mL, and the effect being significant ($p < 0.05$, vs. the A23187 plus PMA value). The histamine release was inhibited approximately 100.0, 51.6, and 77.0% after treatment with the acteoside at 0.1-10.0 μg/mL, and the effect being significant ($p < 0.05$, vs. the compound 48/80 value).

We examined whether acteoside could regulate inflammatory cytokines such as TNF-α and IL-4 in KU812 cells. The inhibition rate of TNF-α and IL-4 production in A23187 plus PMA-stimulated KU812 cells as affected by the acteoside is shown in **Fig. 7**. The acteoside dose-dependently inhibited the production of TNF-α (**Fig. 7A**) and IL-4 (**Fig. 7B**) after treatment for 16 h. The production of the TNF-α was inhibited by about 32.1, 52.1%, and the effect being significant ($p < 0.05$, vs. the A23187 plus PMA). Furthermore, the production of the IL-4 was inhibited by about 14.2, and 80.7% at 1.0 and 10.0 μg/mL treatment, and the effect being significant ($p < 0.05$, vs. the A23187 plus PMA) at 10.0 μg/mL treatment.

Discussion

In this study, phenylethanoid glycosides obtained from *Cistanche tubulosa* did not affect cell viability on RBL-2H3 cells and KU812 cells at the 1.0-10.0 μg/mL treatments. But, acteoside was cytotoxic at the 100.0 μg/mL treatments (**Fig. 2B**), as has been reported by Saracoglu et al. [30] who have shown that acteoside isolated from *Phlomic armeniaca* and *Scutellaria salviifolia* showed cytotoxic effects on dRLh-84, S-180, P-388/D1 cell lines with the IC_{50} 30-221 μg/mL at different cell numbers. Our result was suggests that inhibition effect of actesoide on cell viability at 100 μg/mL treatment, maybe affected by its apoptotic activity.

The immediate-type allergic reaction is involved in many allergic diseases such as asthma, allergic rhinitis and sinusitis. Mast cells play a crucial role in inflammatory and immediate allergic responses. Our data shows that the acteoside has the highest inhibitory effect on the β-hexosaminidase release from IgE-sensitized, antigen-stimulated RBL-2H3 cells compared with other phenylethanoid glycosides at 1.0 μg/mL treatment (**Fig. 3**). Inhibition effect of acteoside on β-hexosaminidase release at 10.0 μg/mL treatment was lower than that at 1.0 μg/mL treatment. As Sugisawa et al. [31] demonstrated, this may be contributed to H_2O_2 induction at high concentrations of acteoside, which might regulated of calcium signals and degranulation on the RBL-2H3 cells [32], influenced to β-hexosaminidase release at 10.0 μg/mL acteoside treatment.

The degranulation of mast cells is closely related to $[Ca^{2+}]i$. The inhibition of Ca^{2+} influx by anti-allergic drugs plays a crucial role in the suppression of degranulation in mast cells. [33-34]. Our results indicate that the intracellular $[Ca^{2+}]i$ level was lower in the acteoside-treated, DNP-BSA-stimulated RBL-2H3 cells (**Fig. 4**), which is consistent with

other reports [34-35], and these results agree with those of **Fig. 3**. We consider from these observations that the decrease in intracellular $[Ca^{2+}]i$ is involved in the inhibitory effect of acteoside on β-hexosaminidase release. Nitric oxide (NO) and H_2O_2 are two major reactive oxygen species (ROS) known in regulation of calcium signal and degranulation of mast cells. ROS are necessary for secretion of β-hexosaminidase and calcium influx, and nicotinamide adenin dinucleotide phosphate (NADPH) oxidase is mainly responsible for ROS production in the IgE-mediated RBL-2H3 cells [29, 32]. The sustained elevation of cytosolic calcium through store-operated calcium entry was totally abolished when the ROS production was blocked. In addition, ROS have some relationship with ß-hexosaminidase and histamine release by protein kinase C (PKC) activation and IgE stimulation in RBL-2H3 cells [34]. Furthermore, Suzuki et al. [36] found that there was a significant correlation between inhibition effects on histamine release and 1, 1-diphenyl-2-picry l-hydrazyl (DPPH) or superoxide anion radical scavenging activities of curcumin-related anti-oxidant compounds. On the other hand, acteoside have free ragical scavenging properties on NO radical and DPPH radical [9, 37]. Also acteoside haw shown scavenging activity in activated human leucocytes [38]. One of the possibility that inhibition effect of acteoside on intracellular calcium release may be affected by its free radical scavenging activities or NADPH oxidase activities.

Acteoside dose-dependently inhibited histamine release on A23187 plus PMA-stimulated KU812 cell (**Fig. 4A**). Acteoside inhibited glutamate-induced intracellular Ca^{2+} influxes resulting in overproduction of NO and reduced formation of ROS [37]. Both PKC and Ca^{2+} signaling pathways are required for histamine and leukotrienes release from mast cells as well as rodent systems [39]. We hypothesized that acteoside may have inhibitory effect on histamine release through Ca^{2+} influx. For this purpose we used A21387 plus PMA to

stimulate KU812 cells and demonstrated histamine release inhibition effect with acteoside. This result supported our hypothesis that acteoside may decrease histamine release from KU812 cells by inhibition of Ca^{2+} influx or PKC activation.

It is believed without doubt that stimulation of mast cells with compound 48/80 initiates the activation of a signal transduction pathway, which leads to histamine release. Senyshyn et al. [40] identified recombinant G subunit markedly synergized phospholipase D activation by compound 48/80 in permeabilized basophilic cells. Compound 48/80-induced secretion is associated with a transient increase in cytosolic Ca^{2+}. This secretion was blocked by the calcium chelator and PKC inhibitor. In the present study, we observed that acteoside inhibited the compound 48/80-induced degranulation from basophilic cells. But, inhibition effect of acteoside on histamine release at 0.1 μg/mL treatment was higher than that 1.0-10.0 μg/mL treatment (**Fig. 4B**). As Lau et al. [41] demonstrated, inhibition effect of acteoside on compound 48/80 induced histamine release may be involved in the anti-inflammation effect of acteoside against vascular permeability-associated edema. Possibly, the acteoside may have several different ways of inhibiting chemical mediator release from basophilic cells, suggesting the complexity of its action. However, in order to reveal the mechanism of histamine release inhibition of this prescription, further studies should be performed.

Among cytokines produced by basophilic cells, TNF-α, IL-4, IL-13, and IL-5 are the key molecules. The reduction of pro-inflammatory cytokines from mast cells or basophilic cells is one of the key indicators of reduced allergic symptom [42]. With regard to TNF-α, the production is mainly regulated by Ca^{2+} influx, but the release process is regulated by additional mechanisms possibly involving activation of PKC in KU812 cells. Inhibition of $[Ca^{2+}]i$ influx is involved in the expression of cytokines in mast cells and basophilic cells [34, 43]. Our result showed that 1.0 and 10.0 μg/mL acteoside reduced TNF-α and IL-4

production from A23187 plus PMA stimulated KU812 cells after treatment for 16 h. Acteoside might inhibit TNF-α and IL-4 production by decreasing the $[Ca^{2+}]i$ level in A23187 plus PMA stimulated KU812 cells. Moreover, our results suggested that the acteoside have anti-allergic effect at the late phase. Confirmation of the effect of acteoside using FcεRI expressing mast cells or basophilic cells is necessary in the future.

In conclusions, we report for the first time that acteoside, echinacoside and cistanoside A extracted from *Cistanche tubulosa* can inhibit the release of β-hexosaminidase from IgE-sensitized BSA-stimulated RBL-2H3 cells. Furthermore, acteoside can inhibit the histamine release, TNF-α, and IL-4 production in a dose-dependent manner on A23187 plus PMA stimulated KU812 cells. These results suggest that acteoside could be a good candidate for the therapeutic treatment of various allergic diseases. The detailed mechanism behind the anti-allergic affect of acteoside is the subject of a future study.

References

[1] *Yoshikawa M, Matsuda H, Morikawa T, Xie H, Nakamura S, Muraoka O*. Phenylethanoid oligoglycosides and acylated oligosugars with vasorelaxant activity from *Cistanche tubulosa*. Bioorg Med Chem 2006; 14: 7468–7475

[2] *Kobayashi H, Oguchi H, Takizawa N, Miyase T, Ueno A, Usmanghani K, Ahmad M*. New Phenylethanoid Glycosides from *Cistanche tubulosa* (SCHRENK) HOOK. f. I. Chem Pharm Bull 1987; 35: 3309–3314

[3] *Tanaka J, Su MH, Shimoda H*. Effect of *Cistanche tubulosa* extract on various brain diseases. Food Style 21 2008; 12: 24–26

[4] *Tanaka J, Su MH, Shimoda H*. Anti-aging functions of *Cistanche tubulosa* extract. Food Style 21 2008; 12: 27–29

[5] *Tanaka J, Kikuchi M, Shan SJ, Su MH, Shimoda H*. Beauty and hair growth functions of *Cistanche tubulosa* extract. Food Style 21 2008; 12: 29–32

[6] *Tanaka J, Shan SJ, Su MH, Shimoda H*. Fat metabolizing effect of *Cistanche tubulosa* extract. Food Style 21 2008; 12: 30–33

[7] *Yoshizawa F, Deyama T, Takizawa N, Usmanghani K, Ahmad M*. The constituents of *Cistanche tubulosa* Schrenk (Hook) f. I I. Isolation and structure of a new phenylethanoid glycoside and a new neolignan glycoside. Chem Pharm Bull 1990; 38: 1927–1930

[8] *Xiong Q, Tezuka Y, Kaneko T, Li H, Tran LQ, Hase K, Namba T, Kadota S*. Inhibition of nitric oxide by phenylethanoids in activated macrophages. Eur J Clin Pharmacol 2000; 14: 137–144

[9] *Sahpaz S, Garbacki N, Tits M, Bailleul F*. Isolation and pharmacological activity of phenylpropanoid esters from Marrubium vulgare. J Ethnopharmacol 2002; 79: 389–392

[10] *He WJ, Fang TH, Ma X, Zhang K, Ma ZZ, Tu PF*. Echinacoside elicits endothelium-dependent relaxation in rat aortic rings via an NO-cGMP pathway. Planta Med 2009; 75: 1400–1404

[11] *Zhang HQ, Weng XJ, Chen LL, Li X*. Effect of *Cistanche tubulosa* (Scheuk) Whight acteoside on telomerase activity and immunity of aging mice. Chinese J Pharmacol Toxicol 2008; 22: 270–273

[12] *Lee JH, Lee JY, Kang HS, Jeong H, Moon CH, Whang WK, Kim SS, Sim C*. The effect of acteoside on histamine release and arachidonic acid release in RBL-2H3 mast cells. J Arch Pharm Res 2006; 29: 508–513

[13] *Diaz AM, Abad MJ, Fernandez L, Silvan AM, Santos JD, Bermejo P*. Phenylpropanoid glycosides from Scrophularia scorodonia: in vitro anti-inflammatory activity. Life Sci 2004; 74: 2515–2526

[14] *Beaven MA, Metzger H*. Signal transduction by Fc receptors: the FcεRI case. Immunol Today 1993; 14: 222–226

[15] *Srivastava D, Arora N, Singh BP.* Current immunological approaches for management of allergic rhinitis and bronchial asthma. Inflamm Res 2009; 58: 523–536

[16] Pelletier C, Gue´rin-Marchand B, Iannascoli F, Marchand B, David AW, Blank U. Specific signaling pathways in the regulation of TNF-α mRNA synthesis and TNF-α secretion in RBL-2H3 mast cells stimulated through the high affinity IgE receptor C. Inflamm Res 1998; 47: 493–500

[17] *Schiwartz LB, Lewis RA, Seldin D, Austen KF*. Acid hydrolases and tryptase from secretory granules of dispersed human lung mast cells. J Immunol 1981; 126: 1290–1294

[18] *Cheong H, Choi EJ, Yoo GS, Kim KM, Ryu SY*. Desacetylmatricarin, an anti-allergic component from *Taraxacum platycarpum*. Planta Med 1998; 64: 577–578

[19] *Ortega E, Schweitzer-Stenner R, Pecht I.* Possible orientational constraints determine secretory signals induced by aggregation of IgE receptors on mast cells. EMBO J 1988; 7: 4101–4109

[20] *Funaba M, Ikeda T, Abe M*. Degranulation in RBL-2H3 cells: regulation by calmodulin pathway. Cell Biol Int 2003; 27: 879–885

[21] *Ohno Y, Tanno K, Yamauchi K, Takishima T*. Gene expression and production of tumour necrosis factor by a rat basophilic leukaemia cell line (RBL-2H3) with IgE receptor triggering. Immunology 1990; 70: 88–93

[22] *Butterfield JH, Weiler D, Dewald G, Gleich GJ*. Establishment of an immature mast cell line from a patient with mast cell leukemia. Leuk Res 1988; 12: 345–355

[23] *Hosoda M, Yamaya M, Suzuki T, Yamada N, Kamanaka M, Sekizawa K, Butterfield JH, Watanabe T, Nishimura H, Sasaki H.* Effects of rhinovirus infection on histamine and

cytokine production by cell lines from human mast cells and basophils. J Immunol 2002; 169: 1482–1491

[24] *Galli SJ, Kalesnikoff J, Grimbaldeston MA, Piliponsky AM, Williams CM, Tsai M*. Mast cells as "tunable" effector and immunoregulatory cells: recent advances. Annu Rev Immunol 2005; 23: 749–786

[25] *Galli SJ, Gordon JR, Wershil BK*. Cytokine production by mast cells and basophils. Curr Opin Immunol 1991; 3: 865–872

[26] *Yamada P, Isoda H, Han J, Talorete TP, Abe Y*. Inhibitory effect of fulvic acid extracted from Canadian *Sphagnum* peat on chemical mediator release by RBL-2H3 and KU812 cells. Biosci Biotechnol Biochem 2007; 71: 1294–1305

[27] *Aase F, Arna, S*. Dantrolene prevents glutamate cytotoxicity and Ca^{+2} release from intracellular stores in cultured cerebral cornical neurons. J. Neurochem 1991; 56: 1075–1078

[28] *Yamada P, Zarrouk M, Kawasaki K, Isoda H,* Inhibitory effect of various Tunisian olive oils on chemical mediator release and cytokine production by basophilic cells. J Ethnopharmacol 2008; 116: 279–287

[29] *Kim Y, Lee YS, Hahn JH, Choe J, Kwon HJ, Ro JY, Jeoung D.* Hyaluronic acid targets CD44 and inhibits FcεRI signaling involving PKCδ, Rac1, ROS, and MAPK to exert anti-allergic effect. Mol Immunol 2008; 45: 2537–2547

[30] *Saracoglu I, Inoue M, Calis I, Ogiwara Y*. Studies on constituents with cytotoxic and cytostatic activity of two Turkish medicinal plants *Phlomis armeniaca* and *Scutellaria salviifolia*. Biol Pharm Bull 1995; 18: 1396–1400

[31] *Sugisawa A, Umegaki K*. Physiological concentration of (-)-epigallocatechin -3-O-gallate (EGCg) prevent chromosomal damage induced by reactive oxygen species in WIL2-NS

cells. J Nutr 2002; 132: 1836–1839

[32] *Suzuki Y, Yoshimaru T, Matsui T, Inoue T, Niide O, Nunomura S, Ra C*. Fc epsilon RI signaling of mast cells activates intracellular production of hydrogen peroxide: role in the regulation of calcium signals. J Immunol 2003; 171: 6119–6127

[33] *Oka T, Sato K, Hori M, Ozaki H, Karaki H*. FcεRI cross-linking-induced actin assembly mediates calcium signalling in RBL-2H3 mast cells. Br J Pharmacol 2002; 136: 837–846

[34] *Tasaka K, Mio M, Okamoto M*. Intracellular calcium release induced by histamine releasers and its inhibition by some anti-allergic drugs. Ann Allergy 1986; 56: 464–469

[35] *Horiuti TM, Zaitsu M, Lambert KC, Grady JJ, Estes DM, Curran EM, Brooks EG, Watson CS, Goldblum RM*. Estrogens potentiate the synthesis and release of mediators of allergy from mast cells by increasing intracellular calcium. J Allergy Clin Immunol 2005; 115: 189

[36] *Suzuki M, Nakamura T, Iyoki S, Fujiwara A, Watanabe Y, Mohri K. Isobe K, Ono K, Yano S*. Elucidation of anti-allergic activities of curcumin-related compounds with a special reference to their anti-oxidative activities. Biol Pharm Bull 2005; 28: 1438–1443

[37] *Koo KA, Kim SH, Oh TH, Kim YC*. Acteoside and its aglycones protect primary cultures of rat cortical cells from glutamate-induced excitotoxicity. Life Sci 2006; 79: 709–716

[38] *Lin LC, Wang YH, Hou YC, Chang S, Liou KT, Chou YC, Wang WY, Shen YC*. The inhibitory effect of phenylpropanoid glycosides and iridoid glucosides on free radical production and b2 integrin expression in human leucocytes. J Pharm Pharmacol 2006; 58: 129–135

[39] *Kim M, Shichijo M, Miura T, Serizawa I, Inagaki N, Nagai H*. Ca^{2+} and protein kinase C signaling for histamine and sulfidoleukotrienes release from human cultured mast cells. Biochem Biophys Res Commun 1999; 257: 895–900

[40] *Senyshyn J, Baumgartner RA, Beaven MA*. Quercetin sensitizes RBL-2H3 cells to polybasic mast cell secretagogues through increased expression of G_i GTP-binding proteins linked to

a phospholipase C signaling pathway. J Immunol 1998; 160: 5136–5144

[41] *Lau CW, Chen ZY, Wong CM, Yao XQ, He ZD, Xu HX, Huang Y*. Attenuated endothelium-mediated relaxation by acteoside in rat aorta: Role of endothelial [Ca^{2+}]*i* and nitric oxide/cyclic GMP pathway. Life Sci 2004; 75: 1149–1157

[42] *Paul WE, Seder RA, Plaut M*. Lymphokine and cytokine production by FcεRI cells. Adv Immunol 1993; 53: 1–29

[43] *Jeong HJ, Hong SH, Lee DJ, Park JH, Kim KS, Kim HM*. Role of Ca^{2+} on TNF-α and IL-6 secretion from RBL-2H3 mast cells. Cell Signal 2002; 14: 633–639

Legends for Figures

Fig. 1 Chemical structure of phenylethanoid glycosides extracted from *Cistance tubulosa*. Acteoside: R^1 = H, R^2 = H; Echinacoside: R^1 = Glc, R^2 = H; Cistanoside A: R^1 = Glc, R^2 = CH_3.

Fig. 2 Cytotoxic effect of three phenylethanoid glycosides from *Cistanche tubulosa* on RBL-2H3 cells and KU812 cells. The percent cell viability was calculated relative to the untreated cells. (A) The cell viability of RBL-2H3 cells. (B) The cell viability of KU812 cells. Results represent one trial (n=8). Three additional trials show similar results. **: Statistically significant from the control at $p < 0.01$.

Fig. 3 Inhibitory effect of three phenylethanoid glycosides from *Cistanche tublosa* on β-hexosaminidase release from RBL-2H3. Ketotifen fumarate (Keto.) was used as a positive control of β-hexosaminidase release. The cells (5.0×10^4 cells/well) in 100 μL were pre-incubated with three kinds of phenylethanoid glycosides at 37^{o}C for 10 min prior to their incubation with DNP-BSA for 1 h. Results represent one trial (n=6-8). Three additional trials show similar results. *: Statistically significant from the control at $p < 0.05$. **: Statistically significant from the control at $p < 0.01$.

Fig. 4 Effect of acteoside extracted from *Cistanche tubulosa* on the $[Ca^{+2}]i$ levels in IgE-mediated RBL-2H3 cells. Ketotifen fumarate salt (Keto.) was used as a positive control of $[Ca^{+2}]i$ influx. IgE-sensitized RBL-2H3 cells (5.0×10^4 cells/well) were incubated with 100 μL of loading buffer including Fluo-3AM for 1 h. The treated cells were incubated with 60 μL recording buffer for 30 min. Changes in $[Ca^{2+}]i$ level induced by DNP-BSA were

measured with a microplate reader. Results represent one trial (n = 3). 2 additional trials show similar results. BSA: Stimulated by DNP-BAS; Keto.: Treatment by ketotifen fumarate salt as positive control.

Fig. 5 Light microscopy photo of KU812 cells in medium (A), after stimulation with A23187 (1 μM) plus PMA (20 nM) (B), 1.0 μg/mL acteoside prior to the stimulation with A23187 plus PMA (C), 10.0 μg/mL acteoside prior to the stimulation with A23187 plus PMA (D). Normal KU812 cells are generally characterized by round shape with fine granules and regular surface. Degranulated basophilic cells become swollen and have many vacuoles, an irregular surface and extruded granules. However, pretreated with acteoside can reduce A23187 plus PMA induced degranulation of KU812 cells. The magnification of the photo was x 200. Bar = 10 μm.

Fig. 6 Inhibitory effect of acteoside on histamine release from KU812 cells after stimulated with A23187 (1 μM) plus PMA (20 nM) or compound 48/80 (10 μg/mL). The cells (2.0 x 10^5 cells/well) in 200 μL were preincubated with acteoside at 37^{o}C for 15 min prior to their incubation with A23187 plus PMA (A) or compound 48/80 (B). Results represent one trial (n=3). Two additional trials showed similar results. *: Statistically significant from the A23187 plus PMA at $p < 0.05$.

Fig. 7 Inhibitory effect of acteoside on TNF-α and IL-4 production by KU812 cells after stimulation with A23187 plus PMA. The KU812 cells (2.0×10^5 cells/well) in 200 μL were pre-incubated with or without acteoside for 15 min and then stimulated with A23187 (1 μM) plus PMA (20 nM) for 16 h. The production of TNF-α (A) and IL-4 (B) was quantified by

ELISA assay. Results represent two trials (n=4). *: Statistically significant from the A23187 plus PMA at $p < 0.05$.

Fig. 1

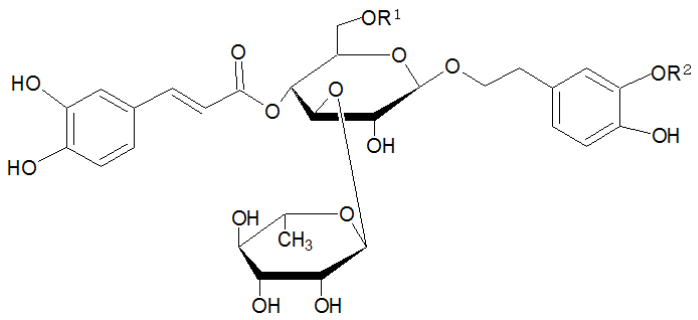


Fig. 2

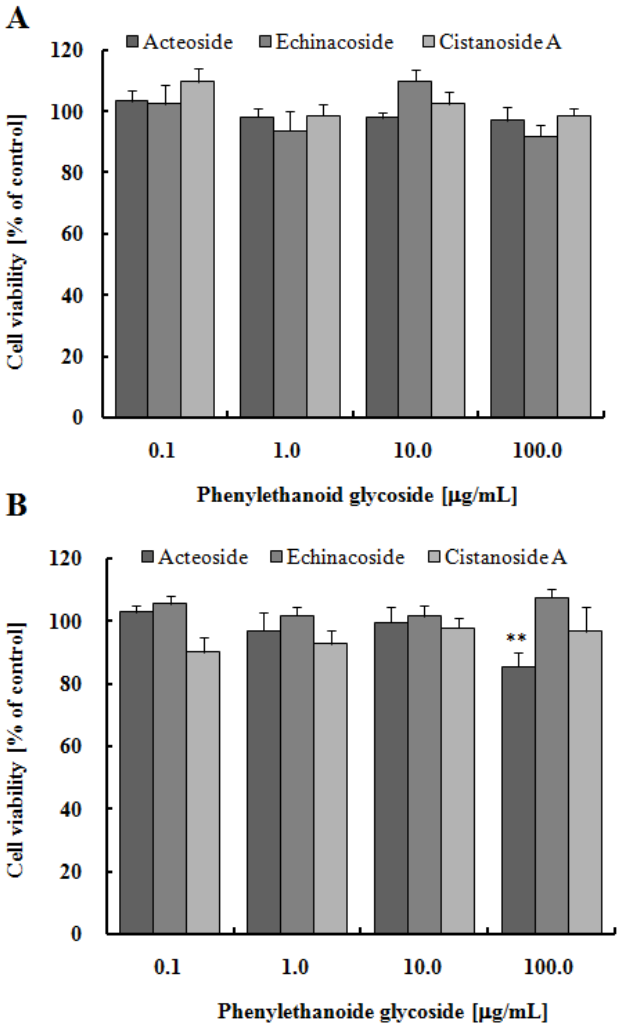

A
Acteoside
Echinacoside
Cistanoside A
120
100
80
60
40
20
0
Cell viability [% of control]
0.1
1.0
10.0
100.0
Phenylethanoid glycoside [μg/mL]
B
Acteoside
Echinacoside
Cistanoside A
120
100
80
60
40
20
0
Cell viability [% of control]
**
0.1
1.0
10.0
100.0
Phenylethanoide glycoside [μg/mL]

Fig. 3

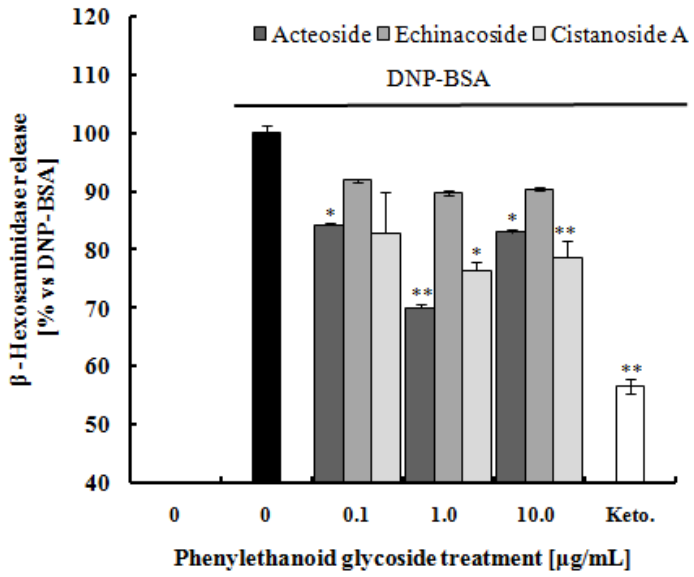

Acteoside
Echinacoside
Cistanoside A
DNP-BSA
β-Hexosaminidase release [% vs DNP-BSA]
120
110
100
90
80
70
60
50
40
*
**
0
0
0.1
1.0
10.0
Keto.
Phenylethanoid glycoside treatment [μg/mL]

Fig. 4

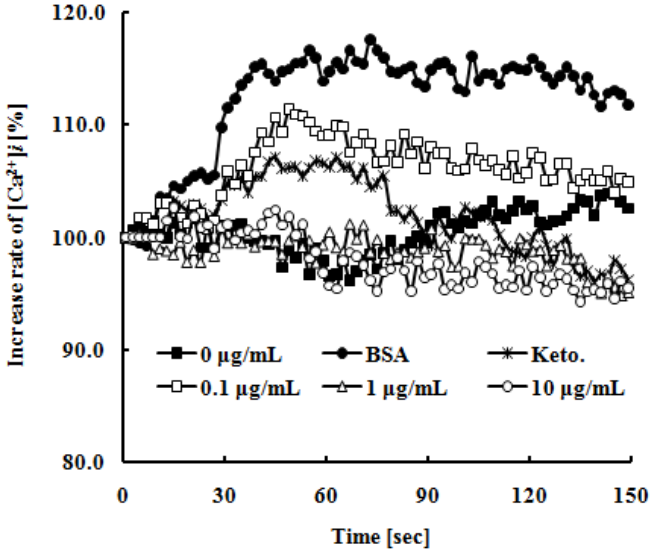

120.0
110.0
100.0
90.0
80.0
Increase rate of [Ca2+]i [%]
0
30
60
90
120
150
Time [sec]
0 μg/mL
BSA
Keto.
0.1 μg/mL
1 μg/mL
10 μg/mL

Fig. 5

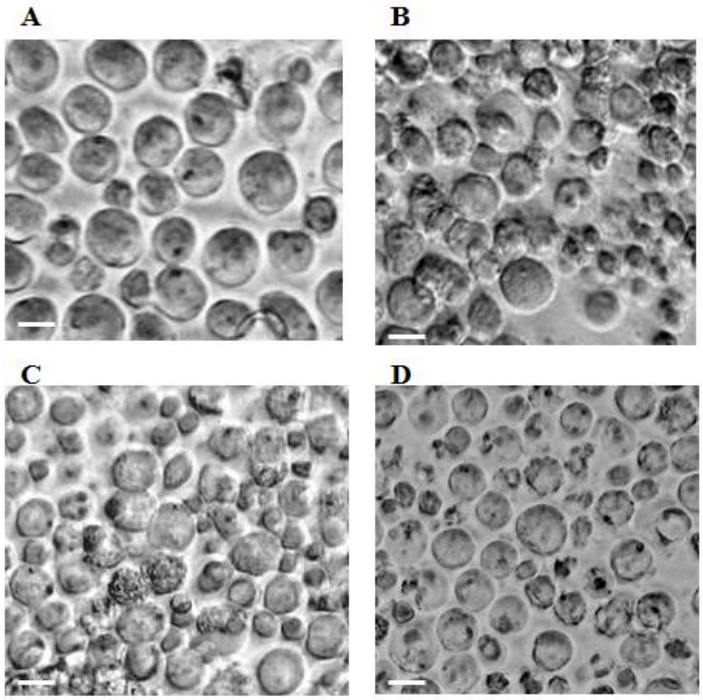


Fig. 6

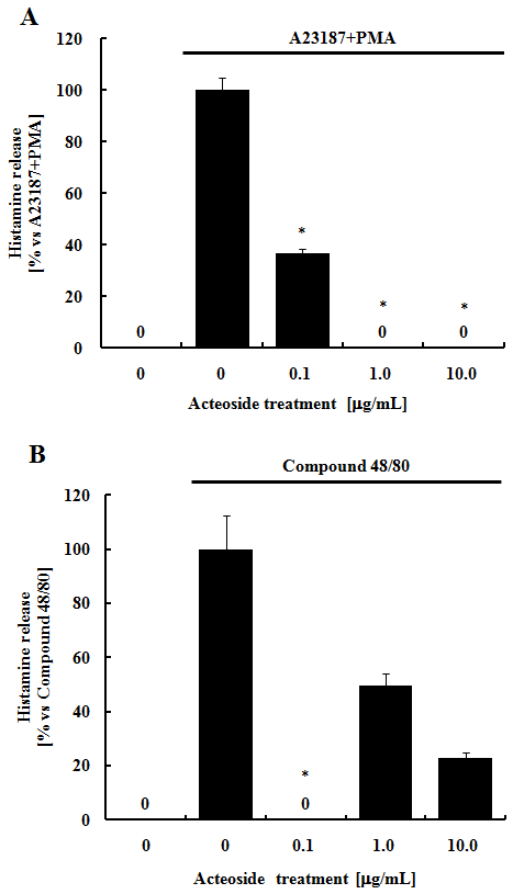
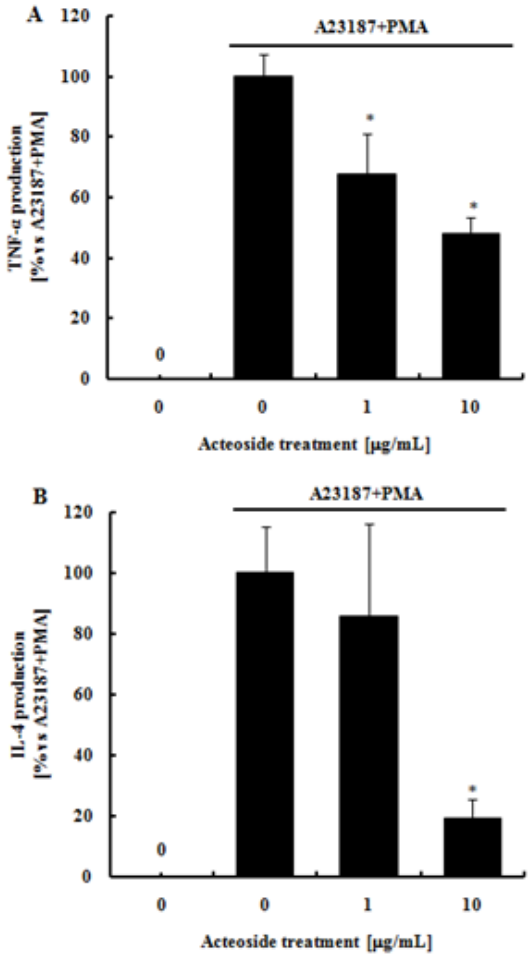

A
A23187+PMA
Histamine release
[% vs A23187+PMA]
120
100
80
60
40
20
0
*
*
*
0
0
0
0
0
0.1
1.0
10.0
Acteoside treatment [μg/mL]
B
Compound 48/80
Histamine release
[% vs Compound 48/80]
120
100
80
60
40
20
0
*
0
0
0
0
0.1
1.0
10.0
Acteoside treatment [μg/mL]

Fig. 7


A
A23187+PMA
TNF-α production [% vs A23187+PMA]
120
100
80
60
40
20
0
0
0
0
1
10
Acteoside treatment [μg/mL]
B
A23187+PMA
IL-4 production [% vs A23187+PMA]
120
100
80
60
40
20
0
0
0
0
1
10
Acteoside treatment [μg/mL]