Stimulation of Dendritic Cell Maturation and Induction of Apoptosis in Leukemia Cells by a Heat-stable Extract from Azuki bean (Vigna angularis), a Promising Immunopotentiating Food and Dietary Supplement for Cancer Prevention

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Abstract

Non-toxic stimulation of dendritic cells (DCs), which are central immunomodulators, may aid the prevention of cancer. Furthermore, induction of apoptosis in cancer cells by anticancer agents contributes to the induction of DC maturation. We previously reported that extracts from Pinus parviflora Sieb. et Zucc pine cone and Mucuna seed induce differentiation of mouse bone marrow cells into mature dendritic cells and also induce apoptosis in various human cancer cell lines. In the present study, we screened 31 kinds of edible beans with biological activity similar to that of extracts from pine cone and Mucuna and found that the heat-stable extract from azuki bean (Vigna angularis) stimulated differentiation of bone marrow cells into immature DCs with the greatest efficacy. The level of IL-6 produced by sequential treatment of DCs with azuki extract and lipopolysaccharide was the highest among the examined beans. Azuki extract also inhibited the growth of human leukemia U937 cells, leading to induction of apoptosis. These results suggest that azuki bean and its extract are immunopotentiating foods that can be used as a dietary supplement for cancer prevention and immunotherapy.

Keywords: Azuki bean - dendritic cells - immunopotentiation - cancer prevention

Introduction

Accumulating evidence indicates that stimulation of anti-cancer immune responses may contribute to the prevention of cancer and also to its management after conventional radiotherapy and chemotherapy (Zitvogel et al., 2008). Dendritic cells (DCs) are central immunomodulators (Banchereau and Steinman, 1998; Jeras et al., 2005), and mature DCs are critical for a potent immune response against cancer cells following radiotherapy and chemotherapy (Vicari et al., 2002; Tesniere et al., 2008). DCs engulf apoptotic tumor cells through recognition of apoptotic characteristics of cancer cells induced by γ-irradiation or treatment with anti-cancer agents such as doxorubicin and mitoxantrone, leading to maturation of DCs and a potent in vivo immune response (Obeid et al., 2007; Apetoh et al., 2008). These findings suggest that combined administration of an inducer of apoptosis in cancer cells and chemical agents with strong differentiation and maturation-inducing activity for DCs might be useful for preventing and/or curing cancer.

We previously reported that an extract (polyphenylpropanoid polysaccharide complex; PPC) from Pinus parviflora Sieb. et Zucc pine cone and an extract from Mucuna pruriens var. utilis seed induce differentiation of human mononuclear cells into DCs in vitro, and these extracts have also been shown to induce apoptosis in human cancer cells (An et al., 2010; Kurokawa et al., 2011). PPC is now commercially available in the United States as a supplement for activating immune cells. Although Mucuna is cultivated in tropical and subtropical regions such as India, south-east Asia, and Brazil, the seed coat is so thick that extended boiling is needed for cooking, and it has not been cultivated as a dietary food in Japan. In the present study, therefore, we screened an additional 31 kinds of edible beans containing components with biological activity similar to that of PPC and Mucuna extract. Results revealed that beans such as azuki bean (Vigna angularis), black bean (Glycine max (L.) Merr.), and flower bean and kougenn bean (both Phaseolus coccineus L.) contain differentiation/maturation-inducing activity for DCs and apoptosis-inducing activity for human leukemia U937 cells. The DC differentiation/maturation-inducing activity of azuki beans was the highest among the examined beans.

Azuki beans have been consumed as a popular food in East Asia for many centuries. In addition, azuki beans have been used in Chinese traditional medicine for treatment of edema and thiamine deficiency. In Japan, various kinds of traditional confectionaries such as youkan (azuki jam cake) and manju (boiled azuki beans) are prepared by boiling azuki beans. The present paper indicates the
Materials and Methods

Reagents and Mice
Beans were purchased from the market located at Honcho 6, Niigata city in Japan. A subspecies of *Mucuna* (*Mucuna harrassio* sieb) was obtained from the Niigata Agricultural Research Institute. RPMI 1640 medium was purchased from Gibco Laboratories (Grand Island, NY). Murine recombinant granulocyte macrophage colony-stimulating factor (rGM-CSF) was provided by PeproTech EC (London, UK). Trypan blue (0.4 %) was from MP Biomedicals, Inc. (Solon, OH). Mouse IL-6 (interleukin-6) and TNF-α ELISA Ready-SET-Go were from eBioscience, Inc (Boston, MA). 2,3-Bis[2-methoxy-4-nitro-5-sulphophenyl]-2H-tetrazolium-5-carboxanilide (XTT), phenazine methosulfate (PMS), Sephadex G-50, and lipopolysaccharide (LPS; from *E. coli* 0111:B4) were provided by Sigma (Saint Louis, MO). *Phellinus linteus* powder was purchased from NIHONDO Co. Ltd. (Tokyo, Japan). Male C57BL/6 mice, 6 weeks old, were purchased from Japan SLC (Hamamatsu, Shizuoka, Japan). The study was approved by the Ethics Committee of Niigata University of Pharmacy and Applied Life Sciences.

Extraction procedure

Extracts of beans and the mushroom *Phellinus linteus* were prepared by the same methods used for the preparation of *Mucuna* extract (Kurokawa et al., 2010). Briefly, beans (50 g) were ground with a mixer and mixed with 0.1 M NaOH solution (500 mL) for 10 min and extracted at 121 °C in an autoclave. After the mixture had cooled to room temperature, it was centrifuged at 3,000 × g for 5 min, and the pellet was removed. The supernatant was neutralized to pH 7 with HCl and the solution was cooled to room temperature, it was centrifuged at 3,000 × g for 5 min, and the pellet was removed. The supernatant was neutralized to pH 7 with HCl and the solution was centrifuged at 10,000 rpm for 10 min. The resulting supernatant was further centrifuged at 40,000 rpm for 30 min. The obtained supernatant was sterilized by filtration (pore size, 0.22 microns).

Cell culture

For preparation of bone marrow (BM)-derived DCs, the femurs and tibiae of C57BL/6 mice were placed in a 90 mm dish with RPMI 1640 on ice after removing muscle with scissors and forceps. The ends of the bones were cut with scissors and the marrow was flushed out using 2 mL RPMI-1640 with a syringe fitted with a 21 gauge needle. The BM cells were centrifuged once and suspended in RPMI-1640 with a syringe fitted with a 21 gauge needle. The BM cells were centrifuged once and suspended in RPMI-1640 with a syringe fitted with a 21 gauge needle. The BM cells were inducing differentiation into immature DCs as we had previously observed for *Mucuna* extract (Kurokawa et al., 2010). Cells were identified under a fluorescence microscope as cells with condensed and fragmented nuclei after staining with Hoechst 33258. Apoptosis was also assessed by measuring the production of mono- and oligonucleosomes using a Cell-Death detection ELISAPLUS kit (Boehringer Mannheim, Mannheim, Germany).

High porosity polymer MCI gel CHP20 chromatography

Extract of azuki beans (500 g) was extracted with an aqueous alkaline solution (3.5 L) as described above, and the extract (168 g in 120 mL) was applied to a column of high porosity polymer MCI gel CHP20 (15 × 100 cm) equilibrated with distilled water and eluted stepwise with 10%, 20%, 50%, and 100% methanol at room temperature at a flow rate of 10 mL/h. Absorbance of the eluted solution was monitored at 275 nm, and fractions were collected until absorbance was reduced to a low and constant level. The eluate was concentrated by rotary evaporation. Each fraction was assayed for growth inhibition of U937 cells and for the production of IL-6 from BM cells, as described above.

Results

Differentiation of DC proceeded in two-steps (Banchereau and Steinman, 1998; Jeras et al., 2005). BM cells were induced to differentiate into immature DCs by cultivation in the presence of GM-CSF and IL-4. Then, stimulation of immature DCs with a microbial component (LPS) or an inflammatory cytokine (TNF-α) led to their differentiation into mature DCs (Banchereau and Steinman, 1998; Jeras et al., 2005). We then examined whether extracts from each of the 31 kinds of beans, which constituted all types commercially available, promoted differentiation of BM cells into immature DCs as we had previously observed for *Mucuna* extract (Kurokawa et al., 2010). As shown in Figure 1, sequential treatment of BM cells with increasing concentrations of azuki extract up to 300 μg extract/mL, then with LPS, produced increasing amounts of IL-6. As shown in Table 1, the level of IL-6...
produced by sequential treatment with 50 μg/mL of azuki extract and LPS was the highest among the examined bean extracts using identical concentrations. Treatment with extracts from kougenn bean and flower bean, then with LPS, also produced significant amounts of IL-6. Although treatment with black bean of Glycine max (L.) Merr. and then with LPS also produced significant amounts of IL-6, extracts from other members of Glycine max (L.) Merr. such as soybean, as well as those from 26 other kinds of bean, failed to produce detectable levels of IL-6.

When BM cells were cultured for 7 days in the presence of GM-CSF and further incubated in the presence of various concentrations of azuki extract for 3 days, virtually no IL-6 was secreted into the culture media (data not shown). This result indicates that the immunological activity of azuki extract is different from that of LPS, which stimulates the maturation of DCs from immature DCs (Kurokawa et al., 2010).

Next, we examined whether other markers associated with mature DCs, such as TNF-α and IL-12, might be produced by sequential treatment with azuki extract and LPS. Such sequential treatment of BM cells with increasing concentrations of azuki extract and LPS stimulated the production of increasing levels of TNF-α and IL-12 (Figure 1).

Production of cytokines induced by azuki extract was compared with that induced by other DC stimulants. As shown in Figure 2, the levels of IL-12 produced by the sequential treatment of BM cells with azuki extract and LPS were significantly lower than those observed following treatment with Mucuna or pine cone extracts. In addition, the ratio of IL-12 to IL-6 in response to azuki extract treatment was lower than that obtained by treatment with Mucuna or pine cone extracts. The levels of TNF-α produced by sequential treatment with azuki extract and LPS were significantly lower than those produced by treatment with the mushroom meshimakobu (Phellinus linteus), which induces functional maturation of DCs in vitro and in vivo (Park et al., 2003; Matsuba et al., 2008). Practically no IL-12 was produced following sequential treatment of BM cells with meshimakobu extract and LPS. These results suggest that sequential treatment with azuki extract and LPS stimulates DCs via a different mechanism than treatment with extracts from Mucuna, pine cone, or meshimakobu.

A low concentration of azuki extract markedly inhibited the growth of human leukemia U937 cells as determined by trypan blue staining (Figure 3). The IC50 value was calculated as 4.7±1.5 μg/mL (Table 1). As shown in Table 1, extracts from black bean, kougenn

**Table 1. Effect of Extracts from Various Beans on Induction of IL-6 Secretion by BM Cells and Growth Inhibition of Human Leukemia U937 Cells**

<table>
<thead>
<tr>
<th>Botanical name</th>
<th>Common name</th>
<th>IL-6 (pg/mL)</th>
<th>IC&lt;sub&gt;50&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vigna angularis</strong></td>
<td>Azuki bean</td>
<td>9737±751</td>
<td>4.7 +1.5</td>
</tr>
<tr>
<td><strong>Mucuna hassjoo sieb</strong></td>
<td><strong>Mucuna</strong></td>
<td>8750+286</td>
<td>2.7 +1.1</td>
</tr>
<tr>
<td><strong>Phaseolus coccineus L</strong></td>
<td><strong>Kougenn bean</strong></td>
<td>2405+389</td>
<td>3.3 +0.8</td>
</tr>
<tr>
<td><strong>Phaseolus coccineus L</strong></td>
<td><strong>Flower bean</strong></td>
<td>1386+130</td>
<td>3.2 +0.8</td>
</tr>
<tr>
<td><strong>Glycine max (L.) Merr.</strong></td>
<td><strong>Black bean</strong></td>
<td>2558+349</td>
<td>8.4 +0.5</td>
</tr>
<tr>
<td><strong>Glycine max (L.) Merr.</strong></td>
<td><strong>Soybean</strong></td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

* BM cells were cultured in a medium containing 50 μg/mL of the extracts from various beans, and the levels of IL-6 secreted into the culture medium were determined by ELISA. Data are expressed as mean ± SD (n = 3). ND: not detectable. No secretion of IL-6 was detected following treatment with extracts from the following species: an additional 5 varieties of Glycine max (L.) Merr., 12 varieties of Phaseolus vulgaris L., 3 varieties of Pisum sativum L., 2 varieties of Canavalia gladiata DC, groundnuts (Arachis hypogaea L.), hiyoko bean (Cicer arietinum L.), sora bean (Vicia L.), and lentil bean (Lens culinaris). IC<sub>50</sub> is the concentration for 50% inhibition of growth of leukemia U937 cells treated with the extracts from various beans. Data are expressed as mean ± SD (n = 3).
Effects of Azuki Bean Extract on Human Leukemia U937 Cells.

Figure 3. Growth Inhibitory and Apoptosis-inducing Effects of Azuki Bean Extract on Human Leukemia U937 Cells. U937 cells were treated with azuki extract at various concentrations for 72 h, and the percentage of viable cells (●) and apoptotic cells (●) were determined. Data are expressed as mean ± SD (n = 3).

Figure 4. Fractionation of Azuki Extract by Column Chromatography and Biological Activity of Separated Fractions. (A) Each methanol fraction (10 μg in 1 μL methanol) was added to 1 mL of culture medium, and U937 cells were cultured for 72 h. The growth inhibitory effect was measured by counting viable cells. Data are expressed as mean ± SD (n = 3). (B) Each methanol fraction (10 μg in 1 μL methanol) was added to 1 mL of the culture medium of BM cells, and then LPS (1 μg/mL) was added. After culturing for 3 days, the level of IL-6 in the culture medium was analyzed by ELISA. Data are expressed as mean ± SD (n = 3).

Discussion

We screened various edible beans, the extracts of which exhibit both DC differentiation/maturation-inducing activity and apoptosis-inducing activity for human leukemia U937 cell lines. We found that the extract from azuki bean had the greatest DC differentiation/maturation-inducing activity among 31 kinds of beans examined. In addition to its DC differentiation/maturation activity, azuki extract also induced apoptosis in human leukemia U937 cells. The results obtained from column chromatography, as shown in Figure 4, indicate that azuki extract contains two components; one with DC differentiation/maturation-inducing activity and the other with apoptosis-inducing activity for leukemia U937 cells. The component which induced differentiation from BM cells to immature DCs was eluted with 100% methanol, while the apoptosis-inducing component for leukemia U937 cells was eluted with 50% methanol. Since engulfment of apoptotic cancer cells stimulates DCs (Apetoh et al., 2008; Obeid et al., 2007), it is possible that these two components of azuki extract have additive or synergistic immunopotentiating effects against cancer cells in vivo. Itoh et al. demonstrated that a hot-water extract of azuki suppressed the growth of human stomach cancer cells in vitro and was effective for reducing murine stomach cancer induced with benzo-α-pyrene in vivo (Itoh et al., 2004). Further investigation of the immunopotentiating and chemopreventive activity of azuki extract in animal cancer models may be warranted.

Mushroom polysaccharides have been widely used as immunostimulants in Asia and as tumor immunotherapy agents in Japan (Borchers et al., 2004). As shown in Figure 2, azuki extract stimulated DCs in a different manner to meshimakobu or pine cone extracts. Thus, the additive or synergistic effects on immune response might be induced by combining these immunopotentiating agents. A major advantage of azuki extract is that it can be cultivated on a larger scale and at a lower cost than mushrooms, and it is also consumed daily across Asia. Thus, azuki beans and azuki extract may be promising immunopotentiating foods, dietary supplements, and adjuvants for cancer prevention and immunotherapy.

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References


