Evaluation of Cytotoxic Activity in vitro of Charantin A Extracted from Momordica charantia

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Abstract: Charantins A is cucurbitane-type triterpene glycoside secondary metabolites derived from Momordica charantia. Here, biological activities of charantin A and mode of action to Spodoptera litura ovary cell line (SpLi-221) were evaluated. We investigated the effects of charantins A on cell growth inhibition compared with charantins B, momordicin I and azadirachtin A. Among them, charantins A showed the most potent activity against SpLi-221 cells with the lowest IC50 values, and in a time- and dose-dependent manner. Moreover, the cell morphology changed after charantin A treatment, including cytoplasm leakage, irregular morphology, and apoptotic bodies. In addition, the flow cytometry assay confirmed that charantin A promoted the occurrence of cells’ G2/M block and apoptosis, as evidenced by an increased ratio of cells in the sub-G1 phase. Furthermore, cell membrane disruption and increase of intracellular calcium levels were observed following charantin A treatment. These findings provide new clues regarding the role of cucurbitane-type triterpene glycosides as potential novel pesticides for pest control.

Keywords: Momordica charantia; tetracyclic triterpene; cytotoxicity; cell cycle; calcium homeostasis; Spodoptera litura. © 2018 ACG Publications. All rights reserved.

1. Introduction

The bitter melon, Momordica charantia L. (Cucurbitales: Cucurbitaceae) is widely used as a vegetable in Asia. A new cucurbitane-type tetracyclic triterpene, charantins A, were isolated from an
ethanolic extract of M. charantia leaves in a previous study [1]. Tetracyclic triterpenes not only accelerate metabolism and anti-cancer in medicine [2,3], but they also have exhibited excellent insecticidal activities to phytophagous pests [4-9], including azadirachtin, momordin I, momordin II, momordin IV, 3β, 7β, 25-trihydroxycurcurbita-5, and 23-diene-19-al 3-Oβ-D-glucopyranoside.

The chemical structure of charantin A is similar to momordin I, momordin II and charantin B (Figure 1). Momordin I and II demonstrate a wide spectrum of biological activities on pest control, including remarkable antifeedant [4], growth inhibition effects [6,10], decreased survival rate [5] and ovipositional defects [5,8]. Moreover, tetracyclic triterpene exert cytotoxic activities on insect cell lines. Proliferation of Spodoptera litura ovary cell line (SL-1) was inhibited by exposure to momordin I and II, resulting in severe alterations in cell morphology, cycle, particularly in the karyotheca and cell membrane [11]. This suggests a main mechanism reducing fecundity of Spodoptera litura adults with atrophied ovarioles. In addition, azadirachtin A restrict proliferation protein synthesis [12] and anti-mitosis effects [13] in the Spodoptera frugiperda cell line (Sf9), as well as potent cytotoxic effects on Sf-1 cells [14]. Charantin B demonstrated significant inhibition effects on proliferation of Ostrinia furnacalis cell lines (Ofh) and can induce necrosis [15].

As insecticidal activity is especially important for pest control, the aim of present study was to clearly detect the biological activity of charantins A. Therefore, in this study, anti-proliferation properties of charantins A in insect cell line SpLi-221 (from ovary of Spodoptera litura) was investigated by compared with charantin B, momordin I and azadirachtin A. Furthermore, charantin A was evaluated effects of morphological alterations, cell cycle arrest and intracellular free calcium levels in SpLi-221 cells.

![Chemical structures of charantin A, charantin B, momordin I and momordin II. Me = CH₃.](image)

**Figure 1.** Chemical structures of charantin A, charantin B, momordin I and momordin II. Me = CH₃.

### 2. Materials and Methods

#### 2.1. Chemicals

Charantin A (purity: 95.6%), charantin B (purity: 95%) and momordin I (purity: 97%) were isolated from M. Charantia leaves in previous study. NMR spectrum and HR-ESI-MS data of three compounds were analysed [1]. Compounds were dissolved in DMSO and diluted with culture medium to the final treatment concentration. The concentration of DMSO was adjusted to 0.5% in the treated groups. Control cultures were performed in the presence of DMSO under the same culture conditions. Azadirachtin A (purity: 98%), MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide),
dimethyl sulfoxide (DMSO), and Pluronic F-127 were purchased from Sigma-Aldrich, Missouri, US. Grace’s insect culture medium and foetal bovine serum (FBS) were purchased from Invitrogen, California, US. The Cell Cycle Detection Kit was purchased from KeyGen BioTech Co. Ltd., Nanjing, China. Hank's Balanced Salt Solution (HBSS) was purchased from Solarbio Technology Co. Ltd., Beijing, China. Fluo 3-AM was purchased from Dojindo Molecular Technologies, Inc., Japan.

2.2. Cell Culture

The cell line TUAT-SpLi-221 (SpLi-221) originated from the culture of the pupal ovaries of Spodoptera litura. It was obtained from the State Key Laboratory of Biocontrol, Department of Biochemistry, School of Life Sciences, Sun Yat-sen University (Guangzhou, China). Cultures were maintained in 4 mL of Grace’s insect culture medium supplemented with 10% foetal bovine serum, penicillin (100 μg/mL), and streptomycin (30 μg/mL) at 27 °C in a CO₂ incubator. Exponentially growing cells were used for the experiments.

2.3. Cell Viability Assay

Cell suspensions (5.0 × 10⁴ cells/mL) were seeded in 96-well culture plates (100 μL/well). After a 24 h pre-incubation period, charantin A, charantin B, momordicin I and azadirachtin A were added to final concentrations of 2.5, 5, 10, 20 and 40 μg/mL, and 0.5% DMSO solution was used as the control (n = 10). After 24, 36, 48 and 60 h of treatment, 20 μL of MTT solution (5 mg/mL) was added to each well and incubated at 27 °C for 4 h. Next, the medium was discarded, and 100 μL of DMSO was added to dissolve the formazan crystals by shaking for 30 min in darkness. The absorbance was measured on a microplate reader (Bio-Rad, USA) at 490 nm. The cytotoxic effects were expressed as the relative percentage of inhibition and calculated as the following:

\[
\text{Cell proliferation inhibition rate (\%) = } \frac{(\text{OD}_{\text{ck}} - \text{OD}_{\text{tr}})}{\text{OD}_{\text{ck}}} \times 100
\]

2.4. Inverted Phase Contrast Microscopy

SpLi-221 cells in the exponential growth phase were plated in a 6-well plate at a density of 1 × 10⁵ cells/well. After 24 h of adherence growth, charantin A was added to a final concentration of 5 μg/mL. The morphological characteristics of SpLi-221 cells were recorded using an inverted phase contrast microscope (Olympus, Japan) after 24 and 48 h. Cells cultured with 0.5% DMSO were used as the control.

2.5. Flow Cytometric Analysis of the Cell Cycle and Apoptosis

SpLi-221 cells (1.0 × 10⁷ cells/dish) were centrifuged and cultured for 12 h for cell cycle synchronisation by serum starvation. After treatment with 5 μg/mL charantin A for 24 and 48 h, cells were harvested and washed in PBS (pH = 7.2) twice and fixed in 70% ice-cold ethanol at 4 °C overnight. Prior to analysis, ethanol was removed by centrifugation (2000 rpm, 5 min), and the cells were washed and incubated in RNase A for 30 min at 37 °C. Next, the cells were stained with PI (50 μg/mL) solution in the dark for 30 min according to the instructions of the cell cycle detection kit prior to analysis using a FACSCalibur machine (Becton Dickinson, USA). A total of 20,000 cells were acquired in each assay. Analysis of cell cycle phase (G0/G1, S and G2/M) and the apoptosis rate were using Cell Quest and Modfit Software (Becton Dickinson) [16]. Each treatment was repeated four times, and cells cultured with 0.5% DMSO were used as the control.

2.6. Intracellular Free \(\text{Ca}^{2+}\) Analysis

Intracellular free calcium analysis was performed using a laser scanning confocal microscope (Leica 780, Germany). SpLi-221 cells (1.0 × 10⁶ cells/dish) were centrifuged and treated with 5 μg/mL charantin A for 12 and 24 h. The supernatants were removed, and cells were rinsed three times in
HBSS (2000 rpm, 5 min). Fluorogenic Ca\textsuperscript{2+} indicator Fluo 3-AM (5 µmol/L) with a 0.05% final concentration of Pluronic F-127 was added to the incubated samples for 45 min at 37 °C. After dye loading, the cells were rinsed with HBSS at least three times. Coverslips of the labelled cells were mounted in 35-mm polystyrene tissue culture dishes (Corning, US) and incubated in HBSS for an additional 30 min at 37 °C prior to imaging. Fluo-3 fluorescence, which can be excited by an argon ion laser at 488 nm, was detected using LSCM. Ca\textsuperscript{2+} concentrations were expressed as the average fluorescence intensity of 50 cells/field, which were randomly selected from three fields in each treatment group of cells. Fluorescence data were analysed using Leica confocal software (ZEN 2012). Cells treated with 0.5% DMSO were used as the control.

2.7. Statistical Analysis

Analyses were performed using SPSS software version 19.0 (IBM Corporation). The cell toxicity regression equation and IC\textsubscript{50} values were performed for the probit analysis. A repeated measures analysis of variance (ANOVA) was performed to evaluate the inhibition of cell proliferation during exposure to different concentrations of the investigated chemicals and exposure to different chemicals at the same concentrations, and the IC\textsubscript{50} values were compared. Differences in the cycle distribution and calcium fluorescence intensity were compared using independent samples t-tests. A value of \( p < 0.05 \) was considered significant. All experiments were performed at least three times for each treatment dose group.

3. Results and Discussion

3.1. Charantin A Inhibited Cell Proliferation in SpLi-221 Cells

Determination of cytotoxicity, a common method to evaluate the biological activities of natural products, is helpful to confirm whether plant extracts have potential pest-resistant properties [17]. To confirm the cytotoxic activities of the isolated compound, SpLi-221 cells were treated with charantin A, charantin B, momordicin I and azadirachtin A for 24, 36, 48, and 60 h, and cell viability was assessed using the MTT assay (Table 1). Figure 2 illustrates cell growth inhibition directly correlates with presented concentrations of charantins A, suggesting a dose-dependent effect. Furthermore, the inhibitory effect seems to be time-dependent. Cell proliferation was nearly completely inhibited when cells were exposed to charantin A at 10 or 20 µg/mL for 24 h. Overall, these results showed that charantins A exerted inhibitory activity on cellular growth, and the inhibitory effects of charantin A were more potent than momordicin I, charantin B and azadirachtin A. Thus, 5 µg/mL charantin A was used in all further experiments.

Table 1. Anti-proliferative activity of tetracyclic triterpene compounds against the SpLi-221 cell lines*  

| Treatment time (h) | Treatment | Toxicity regression equation | IC\textsubscript{50} (µg/mL) | Correlation coefficient |
|-------------------|-----------|------------------------------|-----------------------------|------------------------|
| 24                | Charantin A | \( y=3.754+2.043x \) | 4.64a | 0.897 |
|                   | Charantin B | \( y=2.456+2.545x \) | 9.51b | 0.971 |
|                   | Momordicin I | \( y=3.914+1.663x \) | 5.16a | 0.964 |
|                   | Azadirachtin A | \( y=3.186+0.936x \) | 29.51c | 0.895 |
| 48                | Charantin A | \( y=5.380+0.835x \) | 2.41a | 0.843 |
|                   | Charantin B | \( y=3.795+1.373x \) | 8.05c | 0.952 |
|                   | Momordicin I | \( y=4.913+0.534x \) | 5.36b | 0.803 |
|                   | Azadirachtin A | \( y=2.687+1.927x \) | 15.37d | 0.973 |

Different lowercase letters following the data within column IC\textsubscript{50} indicate a significant difference at alpha = 0.05 level (Tukey’s test, \( p < 0.05 \)).
Evaluation of cytotoxic activity in vitro of Charantin A

3.2. Morphological Effects of Charantin A on SpLi-221 Cells

With the exception of the cell viability assay, determining the morphological changes and characteristics of apoptosis are both useful methods to examine cytotoxicity. Cell morphology can directly reveal cell changes after exposure to a compound. So, inverted phase contrast microscopy was applied to assess morphological changes in SpLi-221 cells induced by 5 μg/mL charantin A (Figure 3). Untreated control cells (Figure 3A, 3C) grew adhered to the culture plate while attached to each other forming a monolayer (arrow a). Control cells typically maintained a smooth surface, and normal size and morphology. On the other hand, after 24 h exposure to charantin A (Figure 3B), some cells were observed floating, and a corrugated surface (arrow b) and holes (arrow c) appeared. Intercellular space was clearly enlarged. After 48 h of exposure, cells showed obvious morphological changes, including cytoplasm shrinkage (arrow e) and leakage (arrow f), irregular morphology (arrow g), and apoptotic bodies with membrane blebbing (arrow d). In addition, cells failed to adhere and were observed resuspended in the culture medium (Figure 3D). These alterations were probably behind the toxic effects described above by MTT. Alteration of cell morphology was similar with SL-1 cell exposure to momordicins I and II [11], or azadirachtin A [14]. Apparently, charantin A can reduce SpLi-221 cell viability by destroying the morphological structure.
3.3. Charantin A Induced Cell Cycle G2/M Arrest in SpLi-221 Cells

Cell proliferation is realized by the cell cycle, and regulation of the cell cycle is a complicated procedure. Cell cycle arrest is closely linked to cell proliferation [18,19]. The sensitivity of cell proliferation is often dependent on the cell cycle [20]. It was reported previously that some cytotoxic compounds directly induce apoptosis by arresting cells in cell phase cycles G0/G1, S, or G2/M prior to inducing apoptosis [14,21,22]. To determine if the inhibition of proliferation and morphological changes induced by charantin A in SpLi-221 cells are involved in cell cycle arrest, we examined the cell cycle phase distribution of the treated cells using flow cytometry. As a consequence, charantin A arrested SpLi-221 cells in the G2/M phase in a time-dependent manner and induced apoptosis, as suggested by an increase of cells at sub-G1 (Figure 4). Charantin A treatment resulted in accumulation of cells in the G2/M phase at 69.31% for 24 h of exposure to 75.80% at exposure for 48 h, with a proportional decrease in percentages at G0/G1 phase. These ratios were significantly different compared with DMSO-treated control cells (Table 2) (G2/M: \( t_{24h} = -8.582, p < 0.01 \); G0/G1: \( t_{24h} = 9.073, p < 0.01 \)). After 48 h of exposure cells at G0/G1 had almost disappeared. Simultaneously, when cells were exposed to charantin A for 24 and 48 h, sub-G1 population increased from 0.91% to 2.64%, an increase of 8.27 and 12.57 fold relative to control cells, respectively. These findings were consistent with the results obtained with treatment with momordicin I and II in SL-1 cells [11]. Consistent with these findings, tetracyclic triterpenoids induced cell cycle arrest in the G2/M phase on insect cells.
**Figure 4.** Flow cytometry analysis of the DNA content and apoptosis of SpLi-221 cells treated with charantin A. (A) and (C) were control cells in drug-free medium for 24 h and 48 h. (B) and (D) were cells treated with 5 µg/mL charantin A for 24 h and 48 h.

**Table 2.** SpLi-221 cell cycle phase distribution analysis

| Treatment   | sub-G1 (apoptosis) | G0/G1 | S         | G2/M       |
|-------------|---------------------|-------|-----------|------------|
| **24 h**    |                     |       |           |            |
| Control     | 0.11±0.05           | 13.65±0.50 | 28.41±0.89 | 57.94±1.00 |
| Charantin A | 0.91±0.18**         | 6.70±0.56** | 24.00±0.70** | 69.31±0.88** |
| **48 h**    |                     |       |           |            |
| Control     | 0.21±0.06           | 16.09±0.14 | 27.36±0.32 | 56.55±0.20 |
| Charantin A | 2.64±0.33*          | 0.14±0.07** | 24.07±0.99 | 75.80±0.96** |

Mean ± SE (n = 3) in the same row followed by * or ** are significantly different (t-test) for the same treatment time (*p < 0.05, **p < 0.01 vs. control).

3.4. Charantin A Results in an Increase in Intracellular Free Ca$^{2+}$ in SpLi-221 cells

Cell proliferation is critically dependent on the regulated movement of ions across various cellular compartments [23]. It is involved in many functions in proliferative cells, including gene expression, protein synthesis, cell secretion, metabolism, cell-cycle progression and apoptosis [24,25]. Numerous research studies have revealed that intracellular calcium homeostasis is a key factor for normal functions and structural integrity of the cell, such as cell proliferation, and the calcium concentration will quickly alter when the cells are stimulated [25-27]. As revealed by LSCM images, concentration of intracellular free calcium increased from exposure to charantin A. At increased exposure times, green fluorescence increased (Figure 5B, D). However, intracellular calcium seems to have remained stable throughout first 24h of exposure (Figure 5A, 5C). Moreover, Figure 5D shows...
details within cells treated with charantin A for 24 h, which when comparing between cells in bright field (Figure 5E) with the merge field (Figure 5F), it seems evident control cells had smooth surface and regular shape, with distinct outlines shown by a slight fluorescence (arrow a). Exposed cells, on the other hand, were uneven and with unclear outlines amidst intense fluorescence (arrow b). Mean individual florescence (N = 450; Figure 5G) at 12h and 24h were significantly higher than negative controls 12 h and 24 h, respectively (**p < 0.01).

Figure 5. Intracellular-free Ca\textsuperscript{2+} changes analysis of SpLi-221 cells treated with charantin A by LSCM. A-D: Fluorescence in dark field. E: bright field. F: merged field. (A) and (C) are control cells in drug-free medium for 12 h and 24 h. (B) and (D, E, F) are cells treated with 5 µg/mL charantin A for 12 h and 24 h. Letter (a) represents normal or healthy cells, and (b) represents damaged cells. G: mean fluorescence intensity of SpLi-221 cells. Data are expressed as the mean ± SE (n = 4) (**p < 0.01 vs. control)

4. Conclusions

In the present work we evaluated the biological activities of tetracyclic triterpene, charantins A, extracted from M. charantia leaves. Charantin A was exhibited potent cytotoxic activity against SpLi-221 cell lines, by inhibited cell proliferation with a time- and dose-dependent manner. Moreover, SpLi-221 cell was destroyed after charantin A treatment, including morphology changed, cell cycle arrested in G2/M phase and apoptosis occurred. The mechanism of action of charantin A with good cytotoxicity is unknown, but disruption of intracellular calcium homeostasis be suggested as a possible factor. The next work will focus on investigating the mechanism of action of these charantins. In a word, these findings provide new clues regarding the role of tetracyclic triterpene natural products as potential novel pesticides for pest control.

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Disclosure statement

The authors declare that they have no conflicts of interest.
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