Chamaejasmin B Decreases Malignant Characteristics of Mouse Melanoma B16F0 and B16F10 Cells

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Chamaejasmin B (CHB), a natural biflavone isolated from Stellera chamaejasme L., has been reported to exhibit anti-cancer properties; however, its effect in melanoma cells is not clear. Here, we aimed to investigate the anticancer effect of CHB in mouse melanoma B16F0 and B16F10 cells. We found that CHB significantly suppressed cell proliferation and promoted cell cycle arrest at G0/G1 phase in B16F0 cells; it also induced cell differentiation and increased melanin content by increasing tyrosinase (TYR) activity and mRNA levels of melanogenesis-related genes in B16F0 cells. Meanwhile, wound closure, invasion, and migration of B16F0 and B16F10 cells were dramatically inhibited. Moreover, CHB significantly increased ROS levels and decreased ΔΨm, resulting in B16F0 and B16F10 cell apoptosis. Finally, in vivo studies showed that CHB inhibited tumor growth and induced tumor apoptosis in a mouse xenograft model of murine melanoma B16F0 and B16F10 cells. Overall, CHB decreases malignant characteristics and may be a promising therapeutic agent for malignant melanoma cells via multiple signaling pathways.

Keywords: chamaejasmin B, melanoma, cell cycle arrest, cell differentiation, metastasis, apoptosis, glycolysis

INTRODUCTION

Cancer is a heterogeneous pathological disease, and ranks second in leading cause of mortality worldwide. Melanoma is a common and highly aggressive skin cancer, leading to >75% of skin cancer deaths but accounting for <5% of skin cancer cases (1). As melanoma is characterized by rapid progression, poor prognosis, and high mortality, various treatments have been developed. Chemotherapy is the optimal treatment for melanoma, although it results in low bioavailability, side effects, poor tumor selectivity, and dose-limiting systemic toxicity (2). In addition, uncontrolled melanoma cell proliferation results in resistance to conventional treatment approaches. Thus, developing a novel treatment or strategy to combat the disease is still needed.

Stellera chamaejasme L. (SCL), known in traditional Chinese medicine as Rui Xiang Lang Du, has been used for treatment of tumors, tinea, stubborn skin ulcers, and so on (3, 4). Chamaejasmin B (CHB) isolated from the root of SCL is the major potent cytotoxic bioflavonoid. It was reported that CHB inhibited many cancers, such as colon cancer, liver carcinoma, osteosarcoma, non-small cell lung cancer and cervical cancer (5). CHB inhibited breast cancer MDA-MB-231 cell metastasis by rebalancing TGF-beta paradox (6). Moreover, CHB also inhibited the growth of multidrug
resistance cells through mitochondrial pathway (7). However, the
effect of CHB toward melanoma is still uncertain. We further
evaluate the anti-melanoma activity of CHB in vitro and in vivo.

MATERIALS AND METHODS
The methods were approved by the Shihezi University Animal Care
and Use Committee (Permit Number A2016-072). Experimental protocols were consistent with the guidelines of
the Association for Assessment and Accreditation of Laboratory
Animal Care International. All studies were designed to
minimize animal numbers and the severity of procedures.

Cell Culture
B16F0 and B16F10 cells were purchased from the China
Center for Type Culture Collection (CCTCC, Wuhan,
China). B16F0 cells were cultured in RPMI 1640 Medium
(Gibco, Grand Island, NY, USA), and B16F10 cells were
maintained in Dulbecco’s Modified Eagle Medium (Gibco,
Grand Island, NY, USA) and supplemented with 10% FBS
(Tianjin Haoyang Biological Manufacture, Tianjin, China),
100 U/mL penicillin (Shandong Sunrise Pharmaceutical, Zibo,
China), and 100 µg/mL streptomycin (Shandong Sunrise
Pharmaceutical, Zibo, China) at 37°C with 5% CO2. All
experiments were performed on logarithmically growing cells.

Analysis of Cell Viability and Apoptosis
SRB (Sigma, St. Louis, MO, USA) was utilized for detecting cell
viability According to the manufacturer’s instructions (8). Viable
cell number was determined using the trypan blue exclusion test
(TBET) (9). Colony-formation assay was used to test cell survival
ability (10). Cell apoptosis was analyzed using nuclear staining
with Hoechst 33258 (Sigma, St. Louis, MO, USA) (9).

Cell Apoptosis, Cycle, ROS, and ∆Ψm
Measurement
According to the manufacturer’s instructions, cell apoptosis
was assessed using Annexin V-fluorescein isothiocyanate
(FITC)/propidium iodide (PI) staining (BD Pharmingen, San
Diego, CA, USA). Cell cycle was determined with PI (0.05
mg/mL) and RNase A (0.5 mg/mL) staining. Intracellular ROS
generation was measured by incubating cells with 10 mmol/L
DCF-DA (Sigma, St. Louis, MO, USA) at 37°C for 30 min.
∆Ψm was measured by JC-1 dye solution (Nanjing Jiancheng
Bioengineering Institute, Nanjing, China) in the dark at 37°C for
20 min. The cells were analyzed using a FACScan flow cytometer
(Becton Dickinson, Franklin Lakes, NJ, USA).

Melanin Content Assessment
In order to detect melanin content, cells and the supernatant were
collected, respectively. Extracellular and intracellular melanin
content was measured according to the previously described
method (11).

TYR Activity Assay
TYR activity was assayed by measuring L-3, 4-
dihydroxyphenylalanine oxidase activity (12), and absorbance
was measured at 405 nm using a microplate reader.

Scratch-Healing Migration Assay
Cells were wounded by scratching with a sterile pipette tip,
treated with CHB, fixed, and photographed. Images were
acquired with an inverted fluorescence microscope (Zeiss,
Axiovert 200, Germany) (13).

Transwell Assays
Migration and invasion were determined using transwell assay
(9, 14). For adhesion assay, B16F0 cells and B16F10 cells were
plated onto the 50 µg/mL matrigel precoated plate and washed
at 1 and 2 h to remove non-adherent cells. The adhered cells
were measured with SRB assay after washed. For migration
assays, B16F0 cells and B16F10 cells were seeded in the top
of the chambers with the non-coated membrane and incubated
overnight. For invasion assays, cells were plated in the top
chamber with matrigel-coated membrane. Medium without serum
or containing 10% FBS was added to the upper chamber
or the lower chamber, respectively. After 24 h, the cells
were fixed in 10% neutral buffered formalin solution for 30 min
and stained with Giemsa. Cells on each insert were calculated using a
microscope (Zeiss, Axiovert 200, Germany).

Quantitative Real-Time Polymerase Chain Reaction
Total RNA was extracted using TRIzol Reagent (Sangong Biotech
Co. Ltd., Shanghai, China). cDNA synthesis was performed using a
RevertAid First Strand cDNA Synthesis Kit (TaKaRa, Shiga,
Japan), and the synthesized cDNA was amplified. The polymerase
chain reaction (PCR) primers (Table 1) were set as indicated,
and reaction conditions were established using 12.5 µL 2×
QuantiFast SYBR (QIAGEN GmbH, Hilden, GERMANY), 3 µL
cDNA template, and 0.5 µL of each primer.

Determination of B16F0 and B16F10 Tumor Growth in vivo
The animals were prepared as previously described (15). We
conducted experiments on C57BL/6 mice based on tumor
suppression and tumor colony formation. Mice were divided
into three treatment groups randomly (five of each group). For
the tumor-suppression experiment, the mice received 1.5, and
3.0 mg/kg of CHB via intragastric administration every day
for 10 days (15). For the tumor colony-formation experiment,
B16F0 and B16F10 cells were pretreated with CHB (0.75, 1.5,
and 3.0 mg/kg) for 24 h and injected subcutaneously into
the right flank of C57BL/6 mice, and colony formation was
observed 12 days after injection. The implanted melanomas
were separated, weighed, and fixed in 10% formaldehyde for at least
24 h and subsequently embedded in paraffin and submitted for
hematoxylin and eosin (H&E) staining (16). TUNEL assays
were performed as previously described (15).
Western Blot Analysis
Total protein (equal amounts) were separated by SDS-PAGE, transferred onto Immobilon®-P Transfer Membrane (Millipore Corporation, Billerica, MA, USA) and blocked with 5% non-fat milk. The membranes were incubated with the respective primary antibodies against Mmp2 (Santa Cruz, CA, USA), Mmp9 (Santa Cruz, CA, USA), Bcl-2 (Santa Cruz, CA, USA), pro-caspase-3 (Cell Signaling Technology, Danvers, MA, United States), cleaved-caspase-3 (Cell Signaling Technology, Danvers, MA, United States), caspase-9 (Santa Cruz, CA, USA) and β-actin (Santa Cruz, CA, USA), and then incubated with the appropriate concentrations of horseradish peroxidase-conjugated secondary antibody. The blots were visualized using the SuperSignal West Pico Chemiluminescent Substrate® (Thermo Scientific, Rockford, IL, USA).

Statistical Analysis
All results are expressed as mean ± standard deviation (SD). Statistical differences among groups were determined using one-way ANOVA followed by Bonferroni multiple comparison test. All analyses were done using SPSS 18.0 statistical software. The results are considered significantly different when P < 0.05 and highly significantly different when P < 0.01.

RESULTS
CHB Inhibits Mouse Melanoma Cell Proliferation
After exposure for 48 h, CHB significantly inhibited the proliferation of B16F0 and B16F10 cells in a concentration-dependent manner (Figures 1A,B). CHB did not remarkably induce cell necrosis on TBET analysis, indicating that CHB did not have a significant lethal effect on B16F0 and B16F10 cells (Figures 1A,B). In addition, there is an obvious decrease in cell density and a distinguishable morphological change in the CHB-treated group (Figures 1C,D). Colony-formation assays revealed that CHB inhibited colony formation of B16F0 cells in a dose-dependent manner (Figures 1E,F). Moreover, the colony size evidently changed following CHB exposure (Figure 1G), suggesting that CHB effectively inhibited the proliferation of B16F0 and B16F10 cells.

CHB Induces G0-G1 Arrest by Regulating mRNA Levels of Cell Cycle-Related Genes
We examined cell cycle progression of B16F0 cells by flow cytometry (Figure 2A) to investigate the inhibitory effect of CHB. Treatment with CHB (9 µg/mL) resulted in an increase at G0-G1 phase (from 51.09 to 79.91%) and a decrease at S (from 40.22 to 18.18%) and G2-M (from 8.69 to 1.91%) phases (Figure 2B), indicating that CHB markedly caused G0/G1 phase arrest in B16F0 cells. Further, we evaluated Cdk4, cyclin D1 (Ccnd1), PcnA and p21 expression in B16F0 cells after CHB treatment and found that compared with the control group, the CHB-treated groups had a significant decrease in Cdk4, Ccnd1, and Pcna mRNA levels and a remarkable increase in the p21 mRNA level (Figure 2C). These results suggest that CHB induced cell cycle arrest at the G0-G1 phase via decreasing the mRNA levels Cdk4, Ccnd1, and Pcna and increasing the mRNA level of p21.

CHB Promotes Melanin Biosynthesis by Increasing TYR Activity
We measured the melanin content of B16F0 cells to investigate the depigmentation activity of CHB. The extracellular (Figure 3A) and intracellular (Figure 3B) melanin contents increased considerably following CHB treatment. Moreover, CHB significantly increased TYR activity in a concentration-dependent manner (Figure 3C). TYR and Tyrp1 mRNA levels dramatically increased in CHB-treated B16F0 cells (Figure 3D), indicating that CHB increased the melanin content in B16F0 cells by upregulating TYR and Tyrp1 mRNA levels.

### TABLE 1 | Primers used for real-time PCR.

| Gene   | Forward primer | Reverse primer | TM (°C) |
|--------|----------------|----------------|---------|
| Ccnd4  | 5′-CATCTCCTCGATATGAGCCAGT-3′ | 5′-CATCTGTTAGCTGTTAGATTCTG-3′ | 57.5    |
| Ccnd1  | 5′-GAGGACACAGAGTGGAGGA-3′ | 5′-TCTGGAGAGGAAAGCTGGTA-3′ | 60.0    |
| PcnA   | 5′-CACCTTAGACTGATTGAGACGAC-3′ | 5′-CACCGAGGAGACTTTATCCAC-3′ | 64.3    |
| P21    | 5′-ATGTCTGTTGATGAGGAAAGCTGGTA-3′ | 5′-TCTGGAGGAAAGCTGGTA-3′ | 60.0    |
| Tyr    | 5′-GAGGACACAGAGTGGAGGA-3′ | 5′-TCTGGAGGAAAGCTGGTA-3′ | 60.0    |
| Tyrp1  | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 5′-TCTGGAGGAAAGCTGGTA-3′ | 60.0    |
| Tyrp2  | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 5′-TCTGGAGGAAAGCTGGTA-3′ | 59.3    |
| Mmp2   | 5′-CGCGGAACAGAAGTGCGAGG-3′ | 5′-CGCGGAACAGAAGTGCGAGG-3′ | 59.3    |
| Mmp9   | 5′-ACCTTGTGAGGACGCTTCAAAG-3′ | 5′-CTTCCTCTGCAGCAGAGGG-3′ | 57.1    |
| Timp1  | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 5′-CTTCCTCTGCAGCAGAGGG-3′ | 60.0    |
| Timp2  | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 5′-CTTCCTCTGCAGCAGAGGG-3′ | 60.0    |
| BcI2   | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 5′-CTTCCTCTGCAGCAGAGGG-3′ | 56.1    |
| Bax    | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 5′-CTTCCTCTGCAGCAGAGGG-3′ | 56.1    |
| caspase-3 | 5′-TCTGGAGGAAAGCTGGTA-3′ | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 56.1    |
| caspase-9 | 5′-TCTGGAGGAAAGCTGGTA-3′ | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 56.1    |
| Gapdh  | 5′-TCTGGAGGAAAGCTGGTA-3′ | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 56.1    |

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| Gene | Forward primer | Reverse primer | TM (°C) |
|------|----------------|----------------|---------|
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| Ccnd1 | 5′-GAGGACACAGAGTGGAGGA-3′ | 5′-TCTGGAGAGGAAAGCTGGTA-3′ | 60.0    |
| PcnA  | 5′-CACCTTAGACTGATTGAGACGAC-3′ | 5′-CACCGAGGAGACTTTATCCAC-3′ | 64.3    |
| P21   | 5′-ATGTCTGTTGATGAGGAAAGCTGGTA-3′ | 5′-TCTGGAGGAAAGCTGGTA-3′ | 60.0    |
| Tyr   | 5′-GAGGACACAGAGTGGAGGA-3′ | 5′-TCTGGAGGAAAGCTGGTA-3′ | 60.0    |
| Tyrp1 | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 5′-TCTGGAGGAAAGCTGGTA-3′ | 60.0    |
| Tyrp2 | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 5′-TCTGGAGGAAAGCTGGTA-3′ | 59.3    |
| Mmp2  | 5′-CGCGGAACAGAAGTGCGAGG-3′ | 5′-CGCGGAACAGAAGTGCGAGG-3′ | 59.3    |
| Mmp9  | 5′-ACCTTGTGAGGACGCTTCAAAG-3′ | 5′-CTTCCTCTGCAGCAGAGGG-3′ | 57.1    |
| Timp1 | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 5′-CTTCCTCTGCAGCAGAGGG-3′ | 60.0    |
| Timp2 | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 5′-CTTCCTCTGCAGCAGAGGG-3′ | 60.0    |
| BcI2  | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 5′-CTTCCTCTGCAGCAGAGGG-3′ | 56.1    |
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| caspase-3 | 5′-TCTGGAGGAAAGCTGGTA-3′ | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 56.1    |
| caspase-9 | 5′-TCTGGAGGAAAGCTGGTA-3′ | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 56.1    |
| Gapdh | 5′-TCTGGAGGAAAGCTGGTA-3′ | 5′-GAGGACACAGAGACTTTATCCAC-3′ | 56.1    |
FIGURE 1 | Effects of CHB on B16F0 and B16F10 cell proliferation. The inhibition rate and lethal ratio of B16F0 and B16F10 cells were determined by SRB assay and the trypan blue exclusion test, respectively (A,B). Morphological changes were observed by phase-contrast microscopy (C,D, magnification, x200). Colonies were photographed and counted under a microscope (E,F, magnification, x200). Effects of various CHB concentrations on colony formation of B16F0 cells (G, magnification, x200). Data were presented as mean ± SD for at least three independent experiments. *P < 0.05, **P < 0.01 compared with the control group cells.
CHB Inhibits Wound Closure, Invasion, and Migration of B16F0 Cells

Invasion and migration are a vital step in the process of tumor metastasis, and it is essential to clarify whether CHB influences the migration and invasion potential of B16F0 cells. First, lower concentrations (0.5, 1.0, and 1.5 µg/mL) of CHB, with no apparent effect on B16F0 cell proliferation, were measured (Figure 4A). Next, we found that B16F0 cells exhibited low adhesion ability following CHB treatment for 1 and 2 h (Figure 4B). Wound closure assays showed a remarkable reduction of migrated cells after 24 h of CHB exposure (Figures 4C,D). In the cell migration assay, CHB significantly suppressed the migration of B16F0 cells (Figure 4E). The number of B16F0 cells migrating through the porous membrane of the transwell insert was reduced from 135.03 ± 3.21 in the control group to 44.10 ± 6.82 in the CHB group (P < 0.01). In the Matrigel invasion assay (Figure 4F), we also found that CHB significantly reduced the average number of cells through the insert membrane, from 218.04 ± 10.62 in the control group to 67.00 ± 7.14 in the CHB group (P < 0.01). Lastly, Timp1 and Timp2 mRNA levels increased, whereas Mmp2 and Mmp9 mRNA and protein levels decreased in CHB-treated cells (Figures 4G–I). Overall, the data suggested that CHB repressed the invasion and migration abilities of B16F0 cells.
CHB Induces B16F0 Cell Apoptosis

To confirm apoptosis induction in B16F0 cells following CHB treatment, fluorescence microscopy was used to examine the morphological changes, which demonstrated a notable change in nuclei with typical characteristics (Figure 5A). Annexin V-FITC apoptosis assay was performed to further distinguish the inhibition of cell proliferation, and the apoptotic rates were increased in B16F0 cells following CHB treatment (Figure 5B). The data demonstrated that the maximum concentration (9 μg/mL) of CHB induced a higher percentage (67.77 ± 3.30%) of apoptosis cells in the CHB group (8.95 ± 1.20%) (Figure 5C). Furthermore, mRNA levels of apoptosis-associated genes were examined by quantitative PCR (qPCR) assay to determine the molecular mechanism of CHB-induced apoptosis. The Bax, caspase-3, and caspase-9 mRNA levels were significantly increased, whereas the Bcl-2 mRNA level was remarkably decreased (P < 0.01) in a dose-dependent manner in the CHB treatment (Figure 5D). Moreover, CHB decreased the expression of antiapoptotic Bcl-2 protein, increased expressions of proapoptotic Bax and caspase-9 proteins and induced caspase-3 cleavage in B16F0 cells (Figures 5E,F). In order to clarify whether CHB-induced apoptosis was through mitochondrial pathway, ΔΨm changes were tested by JC-1 dye following CHB treatment for 2, 8, and 12 h. As shown in Figures 5G,H, CHB broke down mitochondrial integrity. We also examined intracellular ROS level in B16F0 cells following exposure to CHB for 2, 8, 12, and 24 h and found that the ROS level was increased in a dose- and time-dependent manner (Figures 5I,J). The results indicated that CHB induced B16F0 cell apoptosis via the mitochondrial-dependent apoptosis pathway.

CHB Inhibits Tumor Growth and Induces Tumor Cell Apoptosis a Mouse Xenograft Model of B16F0 Cells

Considering that CHB induces mouse melanoma B16F0 cell apoptosis in vitro, we used B16F0 tumor-bearing mice to study whether CHB could suppress tumor progression in vivo. First, the mice were treated with CHB every 2 days after inoculation for 7 days, and there was an obvious difference in tumor-bearing mice following CHB treatment (Figure 6A). Tumor growth inhibition rates were significantly increased in the CHB-treated groups (69.25% for 1.5 mg/kg and 90.38% for 3.0

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**FIGURE 3** | CHB promotes melanin biosynthesis. Effects of CHB on extracellular (A) and intracellular (B) melanin synthesis in B16F0 cells after treatment for 48 h in vitro. (C) Effects of CHB on TYR activities in B16F0 cells. (D) Tyr, Tyrp1, and Tyrp2 mRNA levels were analyzed by qPCR, and relative intensities were normalized by Gapdh mRNA levels. Results were expressed as mean ± SD for three separate experiments. *P < 0.05, **P < 0.01 compared with control group cells.
mg/kg) (Figure 6B). Next, C57BL/6 mice were subcutaneously injected with CHB in the right flank, and colony formation was observed, indicating that CHB inhibited tumor colony formation (Figures 6C,D). In addition, we examined cell morphology of melanoma tumors with H&E staining and observed that the tumor cells had become more irregular following CHB treatment (Figure 6E). Furthermore, the TUNEL assay demonstrated that CHB increased TUNEL-positive cells in tumor tissue in a dose-dependent manner (Figure 6F). The results confirmed that CHB inhibited mouse melanoma B16F0 cell in vitro and vivo.
CHB Decreased Malignant Characteristics of B16F10 Cells

In order to ascertain the effect of CHB on melanoma, we supplement studies on B16F10 cells. CHB treatment (9 µg/mL) caused an increase at G0-G1 phase (from 53.86 to 70.98%) and a decrease at S phase (from 37.03 to 20.78%) and G2-M phase (from 9.11 to 8.14%) (Figure 7A), indicating that CHB markedly caused G0/G1 phase arrest in B16F10 cells. Compared with B16F0 cells, B16F10 cells are metastatic or have higher metastatic potential. Transwell assays examined the effect of CHB on migration and invasion; the cell migration assay indicated that CHB significantly suppressed B16F10 cell migration (Figure 7B). The number of B16F10 cells migrating through the porous membrane of the transwell cell culture insert was reduced from 145.1 ± 9.85 in the control group to 48.27 ± 5.21 in the CHB-treated group (P < 0.01). The Matrigel invasion assay revealed that CHB significantly reduced the average number of migrating cells from 112.95 ± 5.72 in the control group to 30.41 ± 6.22 in the CHB-treated groups (P < 0.01) (Figure 7C), demonstrating that CHB considerably decreased the invasion and migration abilities of B16F10 cells. In addition, the maximum concentration (9 µg/mL) of CHB induced a higher percentage (51.08 ± 2.70%) of apoptosis in B16F10 cells than the control group (4.86 ± 0.91%). The apoptotic rates were significantly increased in B16F10 cells following CHB treatment (Figure 7D). These results implied that the inhibitory effect of CHB might be kind of “universal” to various types of melanoma cells.

CHB Inhibits Tumor Growth in a Mouse Xenograft Model of B16F10 Cells

Lastly, we used tumor-bearing mice models to investigate the effect of CHB on B16F10 tumor progression in vivo. There was a notable difference in tumor-bearing mice after CHB treatment (Figure 8A). The B16F10 tumor growth inhibition rates were 60.38% (1.5 mg/kg) and 72.94% (3.0 mg/kg) in the CHB-treated groups (Figure 8B). In addition, the results of the tumor colony-formation experiment indicated that CHB remarkably inhibited tumor colony formation (Figures 8C,D). Taken together, these results indicated that CHB inhibited mouse melanoma B16F0 and B16F10 cells in vitro and vivo.
FIGURE 5 | CHB induces apoptosis in B16F0 cells. (A) Magnification, x200. Changes in nuclei were stained with Hoechst 33258. (B) Representative images show the apoptotic (Continued) 

DISCUSSION

The key finding of this study is that CHB greatly reduces malignant characteristics and may be a promising therapeutic agent for malignant melanoma cells via multiple signaling pathways. Studies have shown that CHB induces apoptosis in KB and KBV200 cells, possibly via activation of the mitochondrial-dependent intrinsic apoptosis pathway (7). More studies are required to evaluate the effect of CHB as an optimal treatment for melanoma patients because the antitumor mechanisms of CHB on melanoma cells are still not completely understood.

Cell cycle is closely related to many cell fate decisions, such as reprogramming, differentiation, and apoptosis. Cell cycle arrest in G0/G1 by downregulating CDK4 and CCND1 induces apoptosis (17). PCNA showed a function in cell cycle regulation, proliferation and DNA replication (18,19). In addition, P21 is a CDK inhibitor, which has been proposed as a key determinant of cell cycle decisions, and it could bind with several cyclin/CDK complexes and result in S-phase arrest (20). In our study, CHB increased the percentage of B16F0 and B16F10 cells in G0/G1 phase, downregulating Cdk4, Ccnd1 and Pcna mRNA levels and upregulating p21 mRNA levels in B16F0 cells. Thus, CHB inhibited B16F0 cell proliferation in vitro primarily via the inhibition of cell cycle progression by downregulating Cdk4, Ccnd1 and Pcna expressions and upregulating p21 expression in B16F0 cells.

Stimulation of melanogenesis, melanin content and TYR activity are considered to be markers for melanoma cell differentiation (21–23). The process of melanogenesis is initiated by TYR, which plays a key role in melanin synthesis (24). TYR, TYRP1, and TYRP2 are involved in the melanogenesis pathway (25). Our results showed that CHB increased melanin production, significantly upregulated Tyr activity and mRNA expression, and upregulated melanogenesis-related gene expression, indicating that Tyr may play the main role in decreasing malignant characteristics and increasing cell normalization-related properties.

Tissue invasion and metastasis are hallmarks of cancer (26). Metastasis involves an extensive range of steps, in which cancer cells leave the original tumor site and migrate to other body parts (27). Cell migration and invasion play a key role in tumor growth and metastasis (28). Enzymes such as matrix metalloproteinases (MMPs), which cause proteolytic
FIGURE 6 | CHB inhibits growth in B16F0 tumor models in vivo. (A,C) Representative images of tumor suppression and tumor colony formation in tumor-bearing mice. (B,D) Typical picture of isolated tumors and inhibition effect of CHB on tumor suppression and tumor colony formation. (E, magnification, x200) Tumor tissues were stained with H&E. (F, magnification, x200) Tumor tissues were stained using TUNEL. Results were expressed as mean ± SD for three separate experiments. **P < 0.01 compared with control group cells.
FIGURE 7 | Effects of CHB on B16F10 cells. (A) B16F10 cells were harvested to measure cell cycle distribution by flow cytometry and quantitative analysis. (B,C, magnification, ×200) Migration and invasion of B16F10 cells were detected by the transwell assay. Relative invasion ability was determined by counting the cells on the lower surface of the filters in five individual fields. (D) The apoptotic rates of B16F10 cells. Results were expressed as mean ± SD for three separate experiments. *P < 0.05, **P < 0.01 compared with control group cells.
FIGURE 8 | CHB inhibits growth in B16F10 tumor models in vivo. (A,C) Representative images of tumor suppression and tumor colony formation in tumor-bearing mice. (B,D) Typical picture of isolated tumors and inhibition effect of CHB on tumor suppression and tumor colony formation. Results were expressed as mean ± SD for three separate experiments. **P < 0.01 compared with control group cell.
degradation and dysfunctional intracellular interaction, are vital in tumor invasion and metastasis (27). Mmp2 and Mmp9 are closely related to cancer invasion and metastasis, and the inhibition of MMP-mediated cell migration or invasion can be a key strategy against cancer metastasis. TIMPs are inhibitors of active MMPs, including TIMP1 and TIMP2, which are inhibitors of Mmp9 and Mmp2, respectively (29). Our findings demonstrated that CHB inhibited invasion and migration of B16F0 and B16F10 cells. Consistent with the above demonstration, CHB effectively inhibited invasion and migration of B16F0 cells by regulating the mRNA expressions of metastasis-associated proteases.

Apoptosis is another essential bio-process for maintaining cell and tissue homeostasis. Mitochondria not only produce most of the ATP but also regulate metabolism and programmed cell death, thus playing a vital role in cell survival and death (30). In addition, they are known as the main source of ROS in many cell types. Mitochondrial ROS are critical signaling molecules that are involved in many cellular adaptive mechanisms, such as cancer cell migration, differentiation, and apoptosis (31–33). In the current study, we confirmed that increased activity and rapid release of Bax, Casp9, and Casp3 subsequently decrease ΔΨm and increase the intracellular ROS level in B16F0 cells. Therefore, CHB induced mitochondrial-mediated apoptosis through mitochondrial pathway in B16F0 cells.

In summary, CHB induced cell cycle arrest at the G0-G1 phase by downregulating Cdk4, Ccnd1, and PcnA expressions and upregulating p21 expression in B16F0 cells. Besides, tyrosinase activity and melanin content were increased, which indicated melanoma cell differentiation. Invasion and migration of B16F0 cells were also inhibited by regulating the mRNA expressions of metastasis-associated proteases. In addition, CHB induce apoptosis of B16F0 cells through mitochondrial pathway in vitro. CHB also inhibited growth of B16F0 and B16F10 tumor in vivo. Our results provide new insights into the antitumor mechanisms of CHB, indicating that CHB could be a potential natural agent for the prevention and treatment of melanoma. Further investigations regarding the mechanisms of CHB on the malignant phenotype of melanoma cells are necessary, and our study primarily evaluates the potential therapy of CHB in mouse melanoma cells.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

ETHICS STATEMENT

The animal study was reviewed and approved by Shihezi University Animal Care and Use Committee.

AUTHOR CONTRIBUTIONS

LS, YW, and BR: data curation. HR and YD: formal analysis. LS and XY: writing—original draft. QZ, DL, and YL: writing—review and editing.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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