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Investigating the Synergistic Effect of the Cannabis Extract PHEC-66 and Chemotherapeutic Agents on Human Melanoma Cells

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Abstract

Melanoma is a malignant neoplasm that originates from melanocytes. It continues to pose a significant challenge in oncology due to its aggressive nature and limited treatment options. This study investigates the potential additive effects of PHEC-66, a cannabis extract, in combination with conventional chemotherapeutic agents auranofin, docetaxel, and cisplatin on the viability of a range of melanoma cell lines. These combinations were evaluated using the MTT assay on MM418-C1, MM329, C32, and D24 melanoma cells. There was a nuanced response observed when PHEC-66 was combined with docetaxel and auranofin in these cells, suggesting a potential additive effect. Contrastingly, the combination of PHEC-66 with cisplatin elicited an antagonistic effect, wherein the expected cytotoxicity of this drug was compromised. This unexpected interaction may stem from complex interplays between the agents that influence drug uptake, DNA damage response, and cell survival pathways. These findings underscore the importance of careful selection and assessment of drug combinations, as an additive effect and antagonistic interactions can significantly impact therapeutic outcomes. Further studies are warranted to elucidate the molecular mechanisms behind these interactions and to validate these observations using in vivo models.

Keywords: melanoma cells; cannabinoids; auranofin; cisplatin; docetaxel; cytotoxicity

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1. Introduction

Cutaneous melanoma arises from epidermal melanocytes. Sun exposure is the main carcinogen involved in the formation of cutaneous melanoma [1]. Although the prevalence of malignant melanoma does not exceed 5% of all skin cancer types, its survival rate is the lowest, making it the leading cause of skin cancer deaths [2,3].

Current treatment strategies for melanoma include surgery, radiotherapy, and pharmacotherapy. These different approaches are utilized solely and synergistically depending on the stage of the malignancy as well as its pathophysiology [4]. Approximately 50% of melanomas exhibit BRAF mutations, the majority of which are of the $BRAF^{V600E}$ mutation [5]. Other forms of BRAF mutations (V600K, V600D, and V600R) exist, but the prevalent form is V600E [6].

This genetic alteration results in the intrinsic activation of the BRAF-MEK-ERK signalling pathway, commonly referred to as the Mitogen-Activated Protein Kinase (MAPK) pathway [7,8]. Consequently, this activation leads to an increase in both melanoma cell proliferation and survival [7,9]. To inhibit MAPK pathway activation, therapeutic agents such as dabrafenib, vemurafenib, encorafenib, trametinib, and cobimetinib have been developed. These agents target BRAF and/or MEK to inhibit the MAPK signalling pathway [9–11]. Apart from BRAF, other mutations have been observed in melanoma cells; however, these mainly are the result of UV exposure [6,12]. These UV-induced mutations have been found in genes encoding for *RAS (N-, H-, K-)*, *RF1*, *CDKN2A*, *TP53*, *PTEN*, *c-KIT*, *GNAQ/GNA11*, *Akt*, and others [6,12,13].

Melanoma is highly immunogenic and, as a result of its evasive capabilities, this enables it to survive, but its ability to metastasize is the cause of its lethality [14]. Over recent years, immunotherapy has emerged as a transformative approach for the treatment of cancers such as melanoma [15]. Immune checkpoint inhibitors (ICIs) like pembrolizumab, nivolumab, and ipilimumab have demonstrated significant antitumour activity in melanoma [16,17]. These ICIs target specific molecules involved in regulating the immune response, including programmed cell death protein 1 (PD-1), its ligand, programmed death ligand 1 (PD-L1), and cytotoxic T-Lymphocyte antigen 4 (CTLA-4), making them promising treatment options for melanoma and various types of cancer [18,19]. Unfortunately, recent findings have shown that only a subset of patients benefit from this therapy [19]. Researchers have also explored the combination of BRAF/MEK inhibitors with immunotherapy or "checkpoint" effectors, which has shown promise in improving melanoma patient survival [20–22]. Nevertheless, such a regimen was discontinued due to increased toxicity towards non-cancerous cells [21,23]. Recently, talimogene laherparepvec (T-VEC), a modified oncolytic virus derived from HSV-1, has been shown to activate both local and systemic immune responses, resulting in melanoma cell destruction and the activation of tumour-specific T cells [24–26]. Clinical trials have shown the effectiveness of T-VEC on its own or in combination with ICIs such as ipilimumab and pembrolizumab to enhance local and systemic anti-tumour responses against patient melanomas [13,24].

The main primary treatment of cutaneous melanoma is surgical excision, which has been shown to be effective for the removal of in situ and thin melanoma. In situations where surgery is not practical or the where tumour has metastasized, the main form of treatment in chemotherapy or in some cases radiotherapy [27]. One of the first therapeutic drugs used to treat melanoma was dacarbazine [28]; however, it can also affect non-cancerous cells, causing severe side effects [29], resulting in low patient survival rates [30]. Moreover, chemotherapy can be combined with immunotherapies to enhance its efficacy against melanoma cells [31,32]. Docetaxel, a common chemotherapeutic agent that belongs to the taxane group with unique antitumour activity, disrupts microtubule assembly and depolymerization and targets multiple effectors to induce apoptosis [33–35]. This disruption of microtubule depolymerization affects cell cycle progression and signalling pathways, eventually resulting in apoptotic cell death [33,36]. In addition to its antimicrotubular effects, docetaxel also inhibits angiogenesis both in vitro and in vivo by downregulating VEGF (vascular endothelial growth factor) in vascular endothelial cells [37,38].

Cisplatin is a highly effective anticancer agent that is widely used to treat solid tumours such as those found in head and neck, lung, ovarian, leukemia, breast, brain, kidney, testicular, and skin cancers [39,40]. Along with other platinum-based compounds, it is classified as a cytotoxic drug, which damages DNA and its synthesis, preventing these cells from undergoing mitosis, ultimately leading to apoptotic cell death [39]. Cisplatin enhances cellular oxidative stress characterized by reactive oxygen species (ROS) production and lipid peroxidation [19,39]. It also triggers p53 signalling and cell cycle arrest, down-

regulates proto-oncogenes and antiapoptotic proteins, and activates both the intrinsic and extrinsic apoptotic pathways [39]. These mechanisms collectively contribute to this drug's effectiveness in combating melanoma cells. However, recent studies have shown that while a synergistic effect was observed when cisplatin and cannabidiol (CBD) were given to head and neck squamous cell carcinoma cells [41], the opposite effect was seen when this combination was given to melanoma cells [42].

Auranofin interacts with intracellular proteins, inhibiting signalling pathways in cancer progression and promoting cell proliferation [43]. It is a potent inhibitor of mammalian thioredoxin reductases (TrxaRs) in the cytosol and mitochondria, which affects the intracellular redox state, causing oxidative stress and cytotoxic effects in vitro [44,45].

Chemotherapy may provide a more comprehensive and practical approach to combatting cancer and improving patient survival. Some of the reported side effects of treatment include nausea, vomiting, fatigue, hair loss, and a weakened immune system [46]. Additionally, chemotherapy can lead to drug resistance in some cases, making it less effective over time [47,48]. Furthermore, despite an initial response, there is a risk of relapse occurring following treatment [48], emphasizing the need for ongoing research and the development of more targeted and effective therapies to address these challenges in cancer treatment. While survival rates for melanoma patients who are currently receiving combination therapy of ICI and chemotherapeutic drugs are higher than those receiving monotherapy, a significant number of patients do not survive beyond 5 years [27,30]. It has recently been shown that Vitamin D supplementation enhances the survival of melanoma patients receiving combination therapy [27,49].

The efficacy of all these conventional therapies to treat melanoma is limited due to its high metastatic rate and multiple resistance mechanisms coupled with the substantial undesirable side effects of some of these therapies [50–52]. Therefore, the development of new therapeutic strategies to treat this aggressive cancer is critical. The human skin has an endocannabinoid system, composed of enzymes, receptors, and ligands, which regulates skin homeostasis, including the release of inflammatory compounds and cell differentiation and division [52]. This system possesses receptors for multiple compounds, including those derived from plants such as *Cannabis sativa*.

Cannabinoids are important compounds exclusively derived from the plant *Cannabis sativa* that could be potential agents for the treatment of melanoma [50,52,53]. There are more than 80 known cannabinoids that can be obtained from the cannabis plant. Among different cannabinoids, cannabidiol (CBD) and tetrahydrocannabinol (THC) are the most abundant cannabinoids found. The mechanism of cannabinoid action is associated with G-protein coupling via the cannabinoid receptors CB1 and CB2 [52–54]. Through these interactions, cannabinoids regulate the signalling pathways involved in cell division, inhibiting the division or metastasis of cancer cells such as melanoma via inducing autophagic and apoptotic cell death [52–54]. Further information on the mechanism by which CBD exerts its cellular effects can be seen in the reviews by [52,53].

As it is unknown whether an additive effect between cannabinoids and chemotherapeutic drugs exists, in this study, will examine whether an additive effect between docetaxel, cisplatin, and auranofin, in combination with the cannabis extract (PHEC-66), occurs in human melanocytes and melanoma cells. These cell lines were derived from both primary and secondary lesions and either carried the BRAF mutation (V600E) or not to see if there were distinct differences between primary (MM418-C1 and MM329 cells) and secondary tumours (C32 and D24 cells) and if these differences were influenced by the cell's BRAF status ($BRAF^{V600E}$—MM418-C1 and C32 cells; $BRAF^{WT}$—MM329 and D24 cells). The results show that these agents, except for cisplatin and PHEC-66 together, caused a dose-dependent

inhibition of cell survival, predominately in MM418-C1 and MM329 melanoma cells but not in primary human epidermal melanocytes (HEM).

2. Results

2.1. Effects of PHEC-66, Auranofin, Docetaxel, and Cisplatin on Cell Viability

The viability of human melanocytes (HEM) and melanoma cells (MM418-C1, MM329, C32, and D24) exposed to PHEC-66 (0.78–25 μg/mL) for 48 h can be seen in Figure 1A. The two primary melanoma cells (MM418-C1 and MM329 cells) had the lowest IC_{50} values (8.2 and 8.5 μg/mL, respectively), while the secondary melanoma cells (C32 and D24) were more resistant (IC_{50} values 14.4 and 12.8 μg/mL, respectively) to the cytotoxic effects of PHEC-66 (Table 1). However, these melanoma cells were more sensitive to PHEC-66 than the non-cancerous HEM cells (IC_{50} 15.7 μg/mL) [54,55].

Auranofin (0.078–5 μg/mL), like PHEC-66, was shown to be cytotoxic towards these cells (Figure 1B). The secondary melanoma cells, C32 and D24, had the lowest IC_{50} values (both 1.05 μg/mL), while HEM cells (1.41 μg/mL) and the primary melanoma cell lines MM418-C1 and MM329 (1.45 and 1.67 μg/mL, respectively) were less resistant to this drug. Cisplatin (0.078–50 μg/mL) also exerted a cytotoxic effect of these melanocytic-derived cells (Figure 1C). HEM cells (IC_{50} 2.1 μg/mL) were found to be the most sensitive to cisplatin. Of interest was the finding that melanoma cells carrying the BRAF mutation recorded IC_{50} values twice that of cells that did not carry this mutation (Table 1). Docetaxel (0.16–0.60 μg/mL) was shown to be the most cytotoxic of the chemotherapeutic agents tested (Figure 1D). The calculated IC_{50} values for the five cell lines were similar and ranged between 0.4 and 0.6 μg/mL.

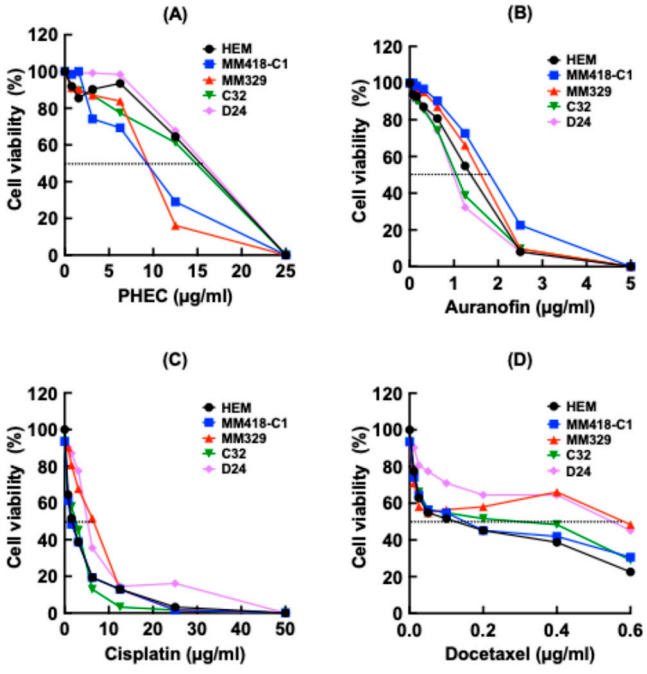

Figure 1. The effects of PHEC-66, auranofin, cisplatin, and docetaxel on the viability of melanocytic-derived cell lines. HEM, MM418-C1, MM329, C32, and D24 cells were treated with (**A**) PHEC-66 (0.78–25 μg/mL), (**B**) auranofin (0.078–5 μg/mL), (**C**) cisplatin (0.78–50 μg/mL), and (**D**) docetaxel (0.16–0.60 ng/mL) for 48 h, and cell viability was measured using the MTT assay and is expressed as a percentage of the untreated controls (100%). Values represent the mean values ± standard deviations of three independent experiments performed in triplicate.

Table 1. A comparison of the efficacy (IC_{50} values) of chemotherapeutic agents against human melanocytes and melanoma cell lines.

	1° Melanocytes	1° Melanoma Cells		2° Melanoma Cells	
Treatment	**HEM (μg/mL)**	**MM418-C1 ($BRAF^{V600E}$) (μg/mL)**	**MM329 ($BRAF^{WT}$) (μg/mL)**	**C32 ($BRAF^{V600E}$) (μg/mL)**	**D24 ($BRAF^{WT}$) (μg/mL)**
PHEC-66	15.71 ± 0.01	8.21 ± 0.01	8.47 ± 0.01	12.77 ± 0.01	14.36 ± 0.01
Auranofin	1.41 ± 0.01	1.67 ± 0.10	1.45 ± 0.10	1.05 ± 0.01	1.05 ± 0.18
Cisplatin	2.10 ± 0.01	2.67 ± 0.01	6.65 ± 0.01	3.07 ± 0.01	5.23 ± 0.01
Docetaxel	0.40 ± 0.01	0.40 ± 0.01	0.60 ± 0.01	0.40 ± 0.01	0.60 ± 0.01

2.2. Effects of Auranofin and PHEC-66 on Cell Viability

Combined modality therapy uses optimal low doses of two agents to achieve maximal antineoplastic effects while reducing potential side effects [47]. In this study, we investigated if there was an additive cytotoxic effect exerted by auranofin with PHEC-66 on a range of melanocytic-derived cell lines. HEM melanocyte cells, as well as MM418-C1, C32, D24 and MM329 melanoma cells, were treated with auranofin (0.078–5 μg/mL) in combination with PHEC-66 (3.12 or 6.25 μg/mL) over 48 h. When determining if an additive interaction between auranofin and PHEC-66 has occurred, their combined activity must be greater than the sum of their stand-alone activities. Based on the findings shown in Figure 2, the combined efficacy of PHEC-66 and auranofin showed mixed results compared to the cumulative efficacy of each compound on their own in these cells. No synergistic effect was observed in melanocytes (HEM) and only at high doses of PHEC-66 in C32 melanoma cells.

We observed a synergistic effect when Auranofin (78 ng/mL) and PHEC-66 (3.12 μg/mL) were added together to MM418-C1 and MM329 cells for 48 h (Figure 3). This cytotoxic effect was significantly ($p < 0.01$) greater for both cells than that observed when these agents were added on their own.

2.3. Effects of Cisplatin and PHEC-66 on Cell Viability

Next, we investigated if there was an additive cytotoxic effect exerted by cisplatin with PHEC-66 on a range of melanocytic-derived cell lines. HEM, as well as MM418-C1, C32, D24, and MM329 melanoma cells, were treated with cisplatin (0.78–50 μg/mL) in combination with PHEC-66 (3.12 or 6.25 μg/mL) over 48 h, as seen in Figure 4. We observed that cisplatin at low doses (2.37–6.65 μg/mL) alone reduced cell viability by ~50% in all the cell lines tested (Figure 4). As the viability of the melanoma cells was reduced by PHEC-66 in a dose-dependent manner, the effects of submaximal doses of cisplatin and PHEC-66 on these cells were investigated. Cisplatin (0.78–50 μg/mL) in the presence or absence of PHEC-66 (3.12 or 6.25 μg/mL) was added to the cells for 48 h. The combined treatment at submaximal doses of PHEC-66 and cisplatin elicited a detectable antagonistic effect against HEM and the melanoma cell lines compared to that seen when these cells were treated with only cisplatin. This result was similar to that seen in melanoma cell lines treated with cisplatin and CBD [42], but not in head and neck squamous cell carcinoma cells [41].

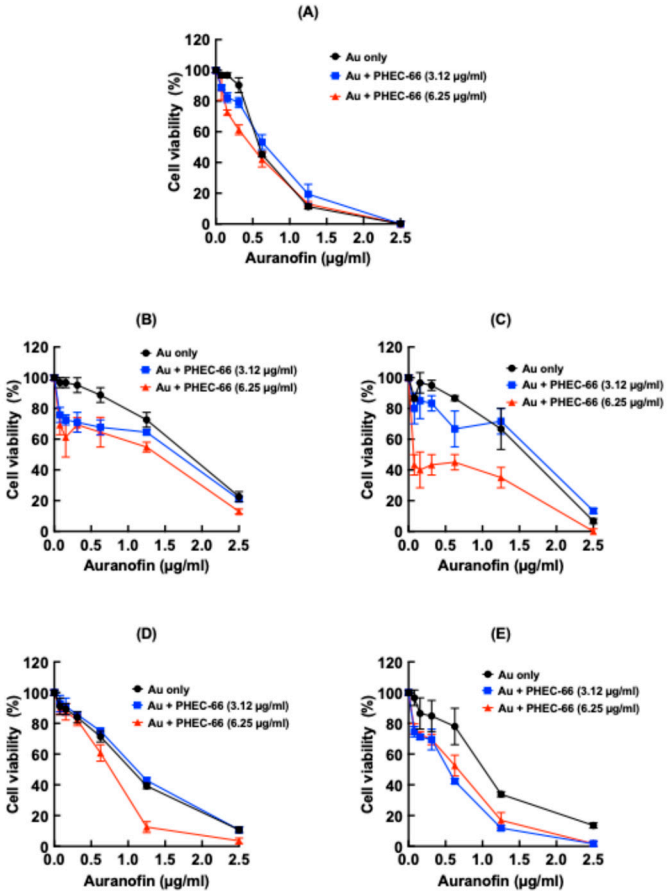

Figure 2. The effect of auranofin plus PHEC-66 on the viability of cultured melanocytic-derived cells. Auranofin (0.078–2.5 μg/mL) alone or in the presence of PHEC-66 (3.12 or 6.25 μg/mL) was added to HEM (**A**), MM418-C1 (**B**), MM329 (**C**), C32 (**D**), and D24 (**E**) cells for 48 h, and viability was measured using the MTT assay and is expressed as a percentage of untreated controls (100%). Values represent the mean values ± standard deviation of three independent experiments performed in triplicate.

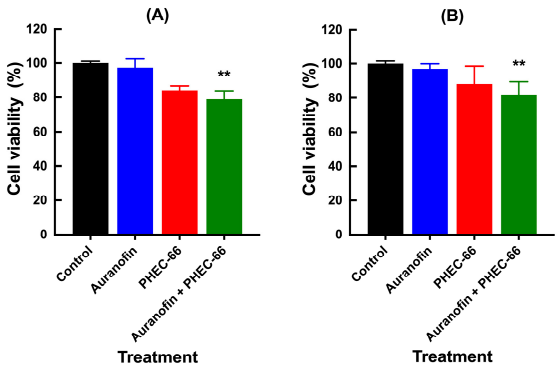

Figure 3. The synergistic effects of auranofin and PHEC-66 on melanoma cell viability. Auranofin (78 ng/mL) and/or PHEC-66 (3.12 μg/mL) were added to MM418-C1 (**A**) and MM329 cells (**B**) for 48 h, and viability was measured using the MTT assay and is expressed as a percentage of untreated controls (100%). Values represent the mean values ± standard deviation of three independent experiments performed in triplicate. Asterisks represent statistically significant differences compared to control, ** $p < 0.01$.

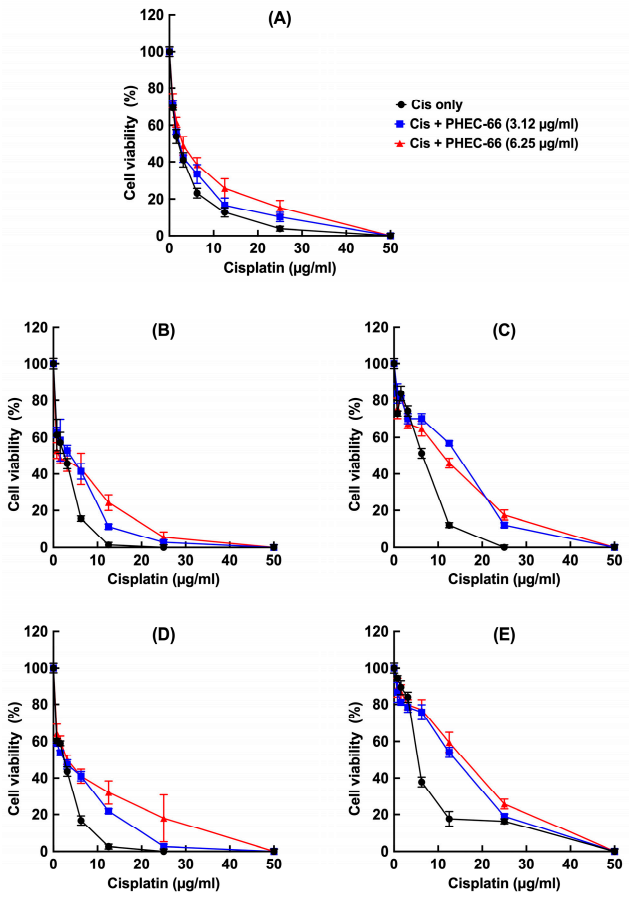

Figure 4. The effects of cisplatin plus PHEC-66 on the viability of cultured melanocytic-derived cells. Cisplatin (0.78–50 µg/mL) alone or in the presence of PHEC-66 (3.12 or 6.25 µg/mL) was added to HEM (**A**), MM418-C1 (**B**), MM329 (**C**), C32 (**D**), and D24 (**E**) cells for 48 h, and viability was measured using the MTT assay and is expressed as a percentage of untreated controls (100%). Values represent the mean values ± standard deviation of three independent experiments performed in triplicate.

2.4. Effects of Docetaxel and PHEC-66 on Cell Viability

HEM, as well as MM418-C1, MM329, C32, and D24 melanoma cells, were treated with increasing concentrations of docetaxel (1.56–600 ng/mL) in combination with two different concentrations of PHEC-66 (3.12 or 6.25 µg/mL) for 48 h (Figure 5). A synergistic effect was observed when MM418-C1, MM329, and D24 melanoma cells were treated with docetaxel in the presence of both concentrations of PHEC-66, but not in HEM or C32 cells (Figure 5A). When MM418-C1 cells were exposed to PHEC-66 and different concentrations of docetaxel, a synergistic effect was seen (Figure 5B). For example, there were a significant reduction ($p < 0.05$) in cell viability at the two concentrations of docetaxel (1.56 or 3.12 ng/mL) that was added to the cells along with 3.12 µg/mL PHEC-66 compared to the untreated controls and cells treated with only docetaxel or PHEC-66 (Figure 6A).

A similar observation was observed in MM329 cells treated with both docetaxel and PHEC-66 (Figures 5C and 6B). However, in C32 cells, a marginal enhanced additive effect was observed following treatment with PHEC-66 plus low doses of docetaxel compared to that observed in those cells treated with only docetaxel or PHEC-66 (Figures 5D and 6C). In the case of D24 cells, a significant additive effect was observed when PHEC-66 (3.120 µg/mL) was combined with docetaxel at all concentrations tested (Figures 5E and 6D).

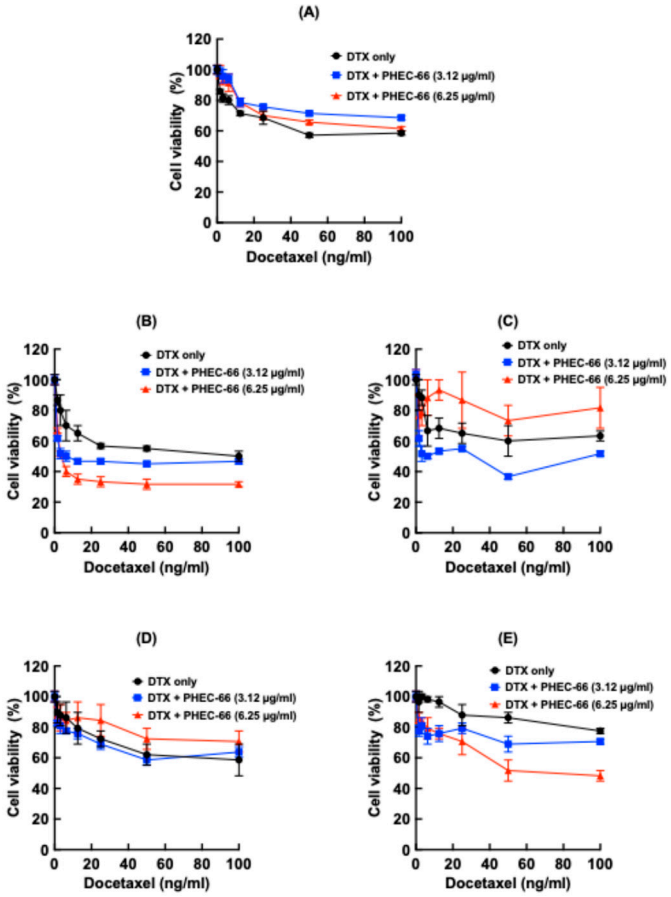

Figure 5. The effects of docetaxel plus PHEC-66 on the viability of cultured melanocytic-derived cells. Docetaxel (1.56–100 ng/mL) alone or in the presence of PHEC-66 (3.12 or 6.25 μg/mL) was added to HEM (**A**), MM418-C1 (**B**), MM329 (**C**), C32 (**D**), and D24 (**E**) cells for 48 h, and viability was measured using the MTT assay and is expressed as a percentage of untreated controls (100%). Values represent the mean values ± standard deviation of three independent experiments performed in triplicate.

Reanalyses of the drug combinations tested in this study were made using SynergyFinder+ (version 3.10.3) (https://synergyfinder.org/#!/, accessed on 28 December 2025) software [56], as seen below in Table 2. Analysis of this data confirmed earlier observations that both auranofin and docetaxel plus PHEC-66 in most cases displayed a synergistic effect against the melanoma cell lines, while cisplatin and PHEC-66 were antagonistic in all the cell lines tested.

Table 2. Analysis of the synergistic effects between PHEC-66 and chemotherapeutic agents when applied to the melanocytic-derived cells (synergistic effect, +; no effect, 0; antagonistic effect, -).

Combination	HEM	MM418-C1	MM329	C32	D24
Auranofin + PHEC-66	+	+	+	+	+
Cisplatin + PHEC-66	-	-	-	-	-
Docetaxel + PHEC-66	-	+	+	0	+

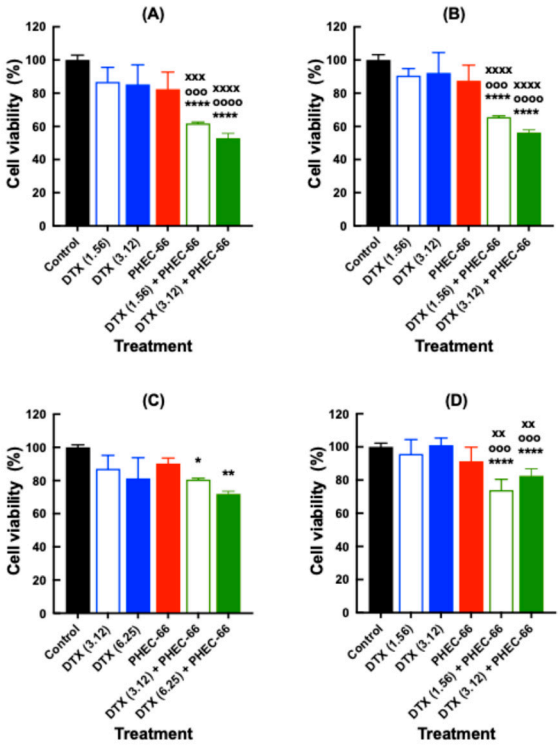

Figure 6. The synergistic effects of docetaxel and PHEC-66 on the viability of cultured melanoma cells. Docetaxel 1.56–6.25 ng/mL) and/or PHEC-66 (3.12 µg/mL) were added to MM418-C1 (**A**), MM329 (**B**), C32 (**C**), and D24 cells (**D**) for 48 h, and viability was measured using the MTT assay and is expressed as a percentage of untreated controls (100%). Values represent the mean values ± standard deviation of three independent experiments performed in triplicate. Statistical differences in treatments compared to untreated controls are represented as * $p < 0.05$, ** $p < 0.001$, **** $p \leq 0.0001$, while statistical differences in the combined treatments compared to only DTX-treated cells are represented as °°° $p < 0.001$, °°°° $p \leq 0.0001$, and statistical differences in the combined treatments compared to only PHEC-66-treated cells are shown as ××, $p < 0.01$, ×××, $p < 0.001$, ×××× $p \leq 0.0001$.

3. Discussion

This study is a continuation of our previous studies on the effect of PHEC-66 on melanoma cells [54,55]. Here, we investigated the additive effect of the chemotherapeutic agents—auranofin, docetaxel, or cisplatin alone or in combination with PHEC-66—on human melanocytes and melanoma cell lines. Exploring these combinations offers novel in vitro insights into PHEC-66′s potential enhancement of therapeutic efficacy against melanoma cells and potentially improved treatment outcomes for these and other cancer patients.

The results of this study reveal a possibility for additive interactions when combining PHEC-66 with auranofin and docetaxel. Administering docetaxel and PHEC-66 caused a significant decline in the cell viability of MM418-C1, MM329, and D24 melanoma cell lines compared to that seen when they were treated with a single agent. Docetaxel disrupts the assembly of microtubule fibres and enhances the stability of these polymers, thereby impeding the depolymerization of these microtubules [57]. These interactions can result in cell cycle interruption and trigger apoptotic cell death. For example, Alsherbiny et al. [37], through a proteomic analysis of MCF7 breast adenocarcinoma cells, showed additive effects when combining CBD with docetaxel. Compared to individual treatments or negative control groups, the combination of CBD and docetaxel demonstrated a notable increase in cell death by apoptosis.

A shotgun proteomics investigation also revealed that CBD treatment enhanced the expression of 121 proteins in MCF7 cells compared to the negative control group [37]. These changes or impairments involve the inhibition of topoisomerase II β and α, cullin 1, V-type proton ATPase, and CDK-6. These processes, coupled with disruptions in energy production and reduced mitochondrial translation, collectively contribute to CBD's cytotoxic effect [37]. These researchers identified that the proteome-wide synergistic molecular mechanisms of CBD, particularly when combined with docetaxel, interfered with the regulation of telomerase, cell cycle progression, topoisomerase I, EGFR1 activity, protein metabolism, TP53-mediated DNA repair, death receptor, and RHO GTPase signalling pathways [37].

Therefore, pairing PHEC-66, a blend containing 60% CBD, with docetaxel can potentially interfere with cellular processes, resulting in significant melanoma cell mortality. This synergistic effect on cell mortality may stem from their combined impact on diverse signalling pathways and cellular functions, resulting in the death of these cells [58]. It is important to note that the observed additive effects might be specific to the MM418-C1, MM329, and D24 cell lines due to their unique characteristics and molecular makeup.

The combination of auranofin and PHEC-66 could have caused an augmented cytotoxic effect, particularly towards MM418-C1 and MM329 melanoma cells. Gambiri et al. [59] provided solid evidence that growth inhibition results from a direct cytotoxic insult occurring at the mitochondrial level. A profound depression of cell respiration was shown to be the main cause of cell death mediated by ROS induction via mitochondrial NADH kinase Pos5 [59]. Wang et al. [45] observed that auranofin inhibited thioredoxin reductase in B16F10 murine melanoma cells, which compromised these cells' antioxidant defences, via increased ROS formation. Auranofin's primary mechanism of action is by inhibiting the redox enzymes, mainly thioredoxin reductase, which in turn is essential for maintaining intracellular ROS levels [59]. Inhibition of these enzymes leads to cellular oxidative stress, resulting in the induction of intrinsic apoptosis in these cells [45,60]. Until recently, auranofin's effectiveness has been compromised by the fact that albumin can displace the TGTA (1-thio-β-D-glucose tetraacetate) ligand on this drug, forming a protein–gold adduct that reduces its efficacy in vivo [61,62]. Recently, it has been shown that supplementing auranofin with TGTA significantly restored its anticancer activities in cells and patient-derived xenograft models [63].

We have shown in our previous studies that PHEC-66, at half its IC_{50} dose, triggered the apoptotic death of MM418-C1, MM329, and MM96L melanoma cells [54,55]. PHEC-66 triggered signalling via both G-protein coupled receptors (CB1 and CB2) in these cells [54]. Following treatment with PHEC-66, at half its IC_{50} dose, we observed a significant increase in intracellular ROS levels [54,55]. Further increasing the PHEC-66 dose to its IC_{50} level significantly increased the intracellular ROS levels in these cells. This resulted in a reduction in the number of cells in S phase, as well as an increase in the sub-G1 peak, as a result of DNA damage after 24 h [54]. By 48 h, we observed a significant increase in the number of cells that had undergone apoptosis as a result. PHEC-66 treatment reduced the gene expression of *Bcl-2* and increased that of *BAX* in these cells, which supports the suggestion that this CBD-rich extract exerts its antiproliferative effect on these melanoma cells by triggering apoptosis [53,54], which is in agreement with the results seen in other studies [52,64,65].

While elevated intracellular ROS levels promotes cell killing [66], some cancer cells, particularly those in advanced stages, are highly adaptive to oxidative stress by upregulating the expression of antioxidants such as glutathione or catalase, which can enhance their survival against more intrusive drug treatments [67]. Hence, exploiting the vulnerability of cancer cells to further ROS generation, i.e., through an additive agent, could be a mechanism that could be used in the treatment of these cells [68].

Cisplatin surprisingly revealed an unexpected result when used in combination with PHEC-66. It is a platinum-based compound which forms crosslinks with the purine bases, which interfere with various DNA-repair mechanisms, causing DNA damage and subsequently inducing apoptosis [39]. Combining cisplatin with PHEC-66 showed an antagonist effect, resulting in less favourable therapeutic outcomes than the separate administration of each substance. Marzeda et al. [42] also observed a similar antagonistic effect when they treated different melanoma cells with cisplatin and CBD. Of interest was that the metastatic derivative of the FM55P melanoma cell line, FM55M2, was shown to be sensitive to this drug combination, as were head and neck squamous cell carcinoma cells [41]. However, in this current study, neither melanocytes (HEM) nor primary (MM418-C1 or MM329) or metastatic secondary melanoma cells (C32 or D24), irrespective of their BRAF status when treated with cisplatin and PHEC-66, showed any synergistic effects. Such polarity between cisplatin and PHEC-66 might result from the different pharmacological mechanisms of these two substances. The reason for why these compounds are antagonistic to each other is unclear and may relate to their interfering with each other's cellular receptor or intracellular signalling pathway activity [69,70]. Uncovering this antagonism between PHEC-66 and cisplatin emphasizes the necessity of a fastidious assessment of drug interactions between different agents. Subsequent investigations should further probe the molecular and cellular mechanisms underpinning this antagonism to gain a comprehensive understanding of these complexities.

Studies on the effects of cannabinoid administration in melanoma patients have shown that these compounds, either individually or as part of combination treatments, reduced tumour growth and promoted apoptosis and autophagy of the patient's melanoma burden [50,52,53,65]. Apart from their anticancer effects, cannabinoids have also been shown to improve quality of life in cancer patients due to different supportive effects like analgesia and/or anti-emetic effects [50,64,65].

It is worth noting that various cell lines often display varying susceptibilities to different treatments due to genetic and molecular disparities [71]. The primary melanoma cells, MM418-C1 and MM329, were both more receptive to the combined treatment of PHEC-66 with auranofin and docetaxel while being resistant to cisplatin plus PHEC-66. This may be related to both having an IC_{50} for PHEC-66 approximately twice that for both secondary melanoma cell lines. This suggests that there are differences in the expression of the CB1 and CB2 receptor expression and/or signalling pathway activities between primary and secondary melanomas. However, we did not detect any differences related to the cell's BRAF status in this study. Further signalling studies using a wide range of melanoma cells are needed to confirm that BRAF does not influence the effect of CBD on melanoma cells. Regarding the chemotherapeutic agents used in this study, similar IC_{50} values were observed for all the melanoma cells, as well as the non-cancerous HEM cells, which are expected as these compounds do not trigger signalling via the MAPK pathway [8]. The results from this study suggest that cannabinoids such as CBD are effective against most melanoma cells, irrespective of their BRAF status, which means that they have the potential to be used in treating all melanoma patients.

This study would have benefitted from using more replicates for each dose of drug that was tested. While this study did investigate primary and secondary melanoma cell lines with differing BRAF statuses, expanding the study to include melanoma cells that possessed other mutations, such as *CDKN2A*, *TP53*, *PTEN*, or *NRAS*, would have shown if the cannabinoid extract exerted a greater effect across all melanoma cells or against a particular subset of cells. Testing PHEC-66 in combination with ICIs on these cells would have shown whether a synergistic effect could be observed between these compounds. The effect of CBD and other cannabinoids in combination with the therapeutic drugs or ICIs

would yield useful information as to which of these compounds in PHEC-66 exerts most of the observed cytotoxic effects.

Further investigations, including detailed molecular studies and in vivo experiments, are necessary to fully understand the mechanisms driving the increased effectiveness of PHEC-66 or other cannabis extracts when combined with auranofin and docetaxel in melanoma cells and, conversely, to understand why the combination of PHEC-66 with cisplatin is antagonistic. The results of these studies may have significant benefits for the treatment of melanomas.

4. Materials and Methods

4.1. Cell Culture

Human melanoma MM418-C1 (primary (1°) melanoma possessing the oncogenic $BRAF^{V600E}$ mutation), MM329 (1° melanoma possessing wild type BRAF ($BRAF^{WT}$)), and C32 (secondary (2°) melanoma possessing the oncogenic $BRAF^{V600E}$ mutation) cells, D24 (2° melanoma possessing wild type $BRAF^{WT}$), and human epithermal melanocytes (HEM), were used in this study. MM418-C1, C32, MM329, and D24 melanoma cells were kindly supplied by Nicholas Hayward and Peter Parsons, Queensland Institute of Medical Research, Brisbane, Australia. HEM cells (Cat No C-12400) were obtained from PromoCell (Heidelberg, Germany). All the cells were cultured in RPMI-1640 tissue culture medium supplemented with 10% (v/v) FBS plus 1% (v/v) penicillin and streptomycin. The cells were incubated at 37 °C in a humidified 5% CO_2 incubator and passaged every 3–4 days until they reached 80–90% confluency.

4.2. Cell Viability Assay

The effect of the chemotherapeutic drugs and PHEC-66 on the viability of HEM, MM418-C1, MM329, MM96L, C32, and D24 cells was evaluated using an MTT assay. The cells (3000–10,000 cells/well) were seeded into 96-well plates and were allowed to adhere for 24 h at 37 °C and 5% CO_2. After this period, the spent tissue culture medium was replaced with a fresh tissue culture medium containing the test compounds dissolved in DMSO (0.06% v/v). The solvent control contained DMSO (0.06% v/v). After 48 h incubation, the medium containing the test compounds was aspirated, 100 µL of culture media containing 5 mg/mL MTT was added to each well, and the cells were incubated for 3 h in the dark at 37 °C. At the end of this period, the media was removed, and 100 µL DMSO was added to each well to solubilize the crystallized formazan product. The plates were read on a microplate reader at 570 nm. The % growth inhibition was calculated as

$$\%\ \text{Cell Viability} = 100 - [(\text{Mean O.D. of the treated cells} \times 100)/\text{Mean O.D. of vehicle-treated cells (DMSO)}]$$

The IC_{50} values were calculated using GraphPad Prism (version 8) (GraphPad Software, Boston, MA, USA). All measurements were performed in triplicate. As for the combination studies, the type of interaction was analyzed using the median-effect analysis, as described by Zheng et al. [56]. The combination synergy score (CSS) and relative inhibition (RI) scores were calculated using SynergyFinder+ software (version 3.10.3) (https://synergyfinder.org/#!/) (accessed on 28 December 2025). The values define the effect of the drug combinations was as follows: synergistic (CSS > RI), no effect (CSS = RI), and antagonistic (CSS < RI).

4.3. Statistical Analysis

The results were analyzed with the one-way analysis of variance (ANOVA) using GraphPad Prism (version 8). For normally distributed data, the means were compared using the one-way analysis of variance (ANOVA) and Tukey's post hoc test. Statistical

values of $p < 0.05$ were considered significantly different. The inhibitory concentration (IC_{50}) of PHEC-66 for cytotoxicity was derived from a nonlinear regression model (curve-fit) based on a sigmoidal dose–response curve (variable) and computed using GraphPad Prism (version 8).

5. Conclusions

In conclusion, the amalgamation of traditional chemotherapy used in melanoma treatment and cannabinoid-based therapies presents a promising avenue in medical treatment. The additive effects observed through combining either docetaxel or auranofin with PHEC-66 highlight the potential for enhanced treatment outcomes for such convoluted and challenging medical conditions. Thiol ligands such as TGTA need to be added to auranofin to maintain its anticancer efficacy if it is used to treat melanoma patients. However, it is crucial to consider the antagonistic effect of cisplatin with PHEC-66. The ability of cannabinoids to complement the established cytotoxic effects of chemotherapeutic agents may result in more effective and tailored treatment strategies. However, it is essential to emphasize rigorous research, comprehensive clinical trials, and a deep understanding of the underlying interactions between the chemotherapeutic agent and cannabinoids to avoid antagonism due to drug interactions witnessed with cisplatin and PHEC-66.

Finally, as the medical landscape continues to evolve, exploring the interplay between these two therapeutic modalities holds immense potential for delivering advanced and effective melanoma patient care based on a comprehensive understanding of medical intervention strategies.

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Abbreviations

Akt	Protein kinase B
CBD	Cannabidiol
CDKN2A	Cyclin-dependent kinase inhibitor 2A
IC_{50}	Half maximal inhibitory concentration
MAPK	Mitogen-activated protein kinase
MTT	3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide
PTEN	Phosphatase and tensin homologue
ROS	Reactive Oxygen Species
TGTA	1-thio-β-D-glucose tetraacetate

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