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(REVIEW ARTICLE)

POTENTIAL EFFECTS OF DANDELION (*Taraxacum officinale* F.H. Wigg.) EXTRACTS ON TYROSINE KINASE SIGNALLING PATHWAYS AND PROSTATE CANCER: A REVIEW OF MOLECULAR MECHANISMS

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ABSTRACT

Prostate cancer is a major malignancy in men, driven by uncontrolled cell proliferation, impaired apoptosis, altered androgen receptor signalling, and dysregulated intracellular growth factor pathways. Understanding these mechanisms is essential for identifying potential therapeutic targets. Receptor tyrosine kinases and their downstream PI3K/AKT/mTOR and RAS/RAF/MEK/ERK pathways are particularly important in regulating cancer cell growth and survival.

Recently, bioactive compounds from natural sources have attracted interest in complementary cancer research and the search for new molecular targets. Dandelion (*Taraxacum officinale* F.H. Wigg.), a member of the Asteraceae family, contains various phytochemicals, including phenolic acids, flavonoids, sesquiterpene lactones, triterpenes, and polysaccharides. Extracts from different plant parts have demonstrated antioxidant, anti-inflammatory, and antiproliferative effects in experimental studies. Notably, some studies indicate that dandelion root extract can induce apoptosis in prostate cancer cells and reduce tumour burden in experimental xenograft models.

Nevertheless, whether these effects result from direct inhibition of tyrosine kinase activity remains unclear. This review examines dandelion's botanical and phytochemical characteristics, the influence of extraction methods on its biological activity, the molecular mechanisms involved in prostate cancer development, and the roles of tyrosine kinases in cellular signal transduction. It also discusses potential interactions between dandelion extracts and the EGFR, PI3K/AKT/mTOR, and MAPK/ERK pathways in light of the available literature.

Overall, current findings indicate that dandelion has biological properties deserving further investigation in prostate cancer research. However, enzyme activity assays, phosphorylation analyses, and molecular validation studies are needed before dandelion can be described as a direct tyrosine kinase inhibitor in future prostate cancer research.

Keywords: *Taraxacum officinale*, Dandelion, Prostate cancer, Tyrosine kinase, EGFR, PI3K/AKT/mTOR, MAPK/ERK, Apoptosis.

1 INTRODUCTION

Cancer is a complex group of diseases arising from deviations from the normal regulatory mechanisms governing cell proliferation, differentiation and programmed cell death. In normal cells, processes such as the progression of the cell cycle, responses to growth factors, DNA damage repair and apoptosis are regulated by specific molecular control systems. Genetic and epigenetic alterations in these systems can enable cells to proliferate uncontrollably and to survive independently of normal tissues. The development of cancer cannot be explained solely by an increase in the rate of cell division; intracellular signalling mechanisms, metabolic changes, inflammation and the tumour microenvironment also play a role in the progression of the disease.

Prostate cancer is a malignancy that originates from the epithelial cells of the prostate gland and causes significant health problems, particularly in older men. Androgen receptor (AR)-mediated signalling is one of the key regulators in the molecular development of the disease. In addition, growth factor receptors, intracellular protein kinases, cell cycle regulators and proteins associated with apoptosis can also influence the biological behaviour of prostate cancer cells. In particular, the dysregulation of the PI3K/AKT/mTOR signalling pathway in prostate cancer and its interaction with the androgen receptor are significant in terms of disease progression and the development of treatment resistance (Raith et al., 2023; Tortorella et al., 2023).

Tyrosine kinases, which play a role in intracellular signal transduction, are enzymes that regulate cellular responses by transferring a phosphate group to the tyrosine amino acid residues of proteins. Receptor tyrosine kinases are located on the cell membrane and transmit growth and differentiation signals from outside the cell into the cell interior. The epidermal growth factor receptor (EGFR), fibroblast growth factor receptors (FGFRs) and the insulin-like growth factor receptor (IGF-1R) are key components of this system. Abnormal activation of these receptors can lead to the sustained activation of signalling mechanisms that promote cell proliferation and survival (Lemmon & Schlessinger, 2010).

With the identification of molecular targets in cancer management, tyrosine kinase inhibitors have become a significant area of research. These drugs aim to limit the growth of tumour cells by inhibiting the enzymatic activity or signalling capacity of specific kinases. However, as the same receptors or signaling pathways are not active in every type of cancer, it is essential to take the tumour's molecular characteristics into account in targeted therapies.

Naturally occurring compounds are also being evaluated in anti-cancer research due to their potential effects on cellular signalling mechanisms. Phenolic compounds, flavonoids and terpenoids found in plants can interact with processes such as oxidative stress, inflammation, the cell cycle and apoptosis. In this context, dandelion (*Taraxacum officinale* F.H. Wigg.) has attracted attention due to its diverse phytochemical constituents and the biological activities reported in various experimental models (Schütz et al., 2006; Di Napoli & Zucchetti, 2021).

Studies reporting that dandelion root extract can induce apoptosis in prostate cancer cells represent an important starting point for investigating the plant's potential effects on this disease. Sigstedt et al. (2008) investigated the effects of dandelion aqueous extracts on the growth and invasion of breast and prostate cancer cells. In a subsequent study, Nguyen et al. (2019) reported that dandelion root extract can increase apoptosis in prostate cancer cells and reduce tumour burden in experimental tumour models.

However, it is not yet fully understood through which molecular targets the biological effects of dandelion on prostate cancer cells are mediated. In particular, whether tyrosine kinase activity is directly inhibited remains a key research question.

The aim of this review is to evaluate the phytochemical properties of dandelion and its experimental effects on prostate cancer. It also aims to explain the functions of tyrosine kinases in cancer cells and to discuss, in the light of the literature, the possible relationships between plant extracts and molecular signalling pathways such as EGFR, PI3K/AKT/mTOR and MAPK/ERK.

2 BOTANICAL AND TAXONOMIC CHARACTERISTICS OF THE DANDELION

The dandelion is a perennial herbaceous plant belonging to the Asteraceae family. The species, known as *Taraxacum officinale* F.H. Wigg., is found in various regions of the world, particularly in Europe and Asia. The plant, which also grows naturally in Turkey, is able to adapt to different climatic and soil conditions.

The plant's characteristic morphological features include a taproot system developing underground, leaves arranged in a rosette at the base, and a yellow flower head. The root, leaf and flower parts of the plant are utilised in traditional applications, and the chemical compositions of these parts may differ from one another.

The traditional use of dandelion is particularly associated with digestive disorders, diuretic applications and certain liver conditions. However, information on traditional use should not be regarded as evidence of modern clinical efficacy. In order to explain the plant's biological properties from a scientific perspective, its chemical composition and experimental effects must be examined separately. Demirci et al. (2020) evaluated the botanical characteristics, chemical composition and use of dandelion in traditional medicine; they provided information on the plant parts listed in various pharmacopoeias and their traditional uses. Schütz et al. (2006), meanwhile, comprehensively addressed the phytochemical and pharmacological properties of the genus Taraxacum.

The chemical composition of the plant may vary depending on the geographical region in which it is grown, the harvest period, soil characteristics, the age of the plant, drying conditions and the extraction method. For this reason, the characteristics of the plant material must be taken into account when comparing the results of biological activity obtained in different studies.

3 THE PHYTOCHEMICAL COMPOSITION OF DANDELION

In order to understand the biological properties of dandelion, it is important to evaluate the chemical compounds it contains. Secondary metabolites, which are present in varying proportions in the plant's roots, leaves and flowers, can influence the biological activity of the extracts. Phenolic acids, flavonoids, sesquiterpene lactones, triterpenes, phytosterols and polysaccharides are the prominent groups of compounds in this context (Schütz et al., 2006; Di Napoli & Zucchetti, 2021).

3.1 Phenolic compounds

Phenolic compounds are chemical compounds commonly found in plants that contain hydroxyl groups attached to an aromatic ring. Owing to their antioxidant properties, these molecules play an important role in research into free radical formation and cellular oxidative balance.

Phenolic compounds such as caffeic acid, chlorogenic acid and chicoric acid have been reported in dandelion. These compounds may be present in varying amounts depending on the plant part and extraction conditions. The antioxidant properties of phenolic structures are related to the capacity of hydroxyl groups to donate electrons or hydrogen. Yılmaz and Gözcü (2025) evaluated the phenolic and flavonoid content and antioxidant capacity of dandelion root extract. In the study, the total phenolic content of the root extract prepared using 70 per cent methanol was reported as 23.58 ± 0.97 mg gallic acid equivalent/g extract, whilst the total flavonoid content was reported as 7.76 ± 0.81 mg quercetin equivalent/g extract. The results obtained from DPPH, ABTS and FRAP analyses indicate that the dandelion root extract possesses measurable antioxidant capacity.

The importance of phenolic compounds in cancer research is not limited solely to their free radical-scavenging properties. Studies on various plant compounds have shown that certain phenolic structures can interact with intracellular signalling proteins, inflammation modulators and mechanisms associated with the cell cycle. However, these general properties do not prove that dandelion extract inhibits a specific tyrosine kinase.

3.2 Flavonoids

Flavonoids are polyphenolic compounds commonly found in plant sources. Quercetin, luteolin, apigenin and their glycoside derivatives are among the known members of this group. Various flavonoid compounds have been identified in different parts of the dandelion.

The biological activities of flavonoids are related to their chemical structure, the position of hydroxyl groups, their glycosylation status and their bioavailability within cells. In addition to the antioxidant properties of these compounds, their effects on inflammation-related enzymes and intracellular signalling mechanisms are also being investigated.

Determining the flavonoid content of dandelion extracts may assist in the chemical interpretation of results obtained in anti-cancer research. In particular, comparing the flavonoid profiles of extracts prepared using different solvents is important for assessing which chemical fractions may be associated with biological activity.

3.3 Sesquiterpene lactones

Sesquiterpene lactones are terpenoid derivatives found in plants and studied for their biological activities. Taraxinic acid derivatives, taraxacoside and similar sesquiterpene lactone compounds have been reported in the roots and above-ground parts of dandelion.

The chemical structures of these compounds may be significant in terms of their interaction with cellular proteins. In particular, the effects of certain sesquiterpene lactones on mechanisms associated with inflammation and cellular stress responses have been investigated.

However, in order to directly attribute a biological activity exhibited by crude dandelion extract to a specific sesquiterpene lactone, the compound must be isolated, its structure confirmed, and it must be experimentally evaluated as a pure compound.

3.4 Triterpenes and phytosterols

Triterpenes and phytosterols constitute another important component of the chemical composition of dandelion. Taraxasterol, β-sitosterol and stigmasterol are among the compounds considered in this context.

The lipophilic properties of these compounds may influence the quantities obtained, depending on the polarity of the solvents used during extraction. Therefore, extracts prepared using water alone should not be expected to have the same chemical profile as those obtained using ethanol or other organic solvents.

Triterpenes and phytosterols are being investigated in various biological systems in relation to inflammation, cell membrane regulation and cellular metabolism. These compounds must also be taken into account when explaining the potential effects of dandelion extracts on prostate cancer.

3.5 Inulin and other polysaccharides

Inulin is a polysaccharide found in dandelion root and composed of fructose units. This compound, which exhibits prebiotic properties, is one of the plant's components evaluated from both nutritional and pharmacological perspectives.

Research has been conducted into the antioxidant and various biological activities of polysaccharide fractions derived from dandelion root. However, there is insufficient evidence to demonstrate that polysaccharides directly inhibit tyrosine kinase activity in prostate cancer cells. Therefore, when evaluating the anti-cancer effects of the plant's phytochemical constituents, the biological properties of each chemical group must be examined separately.

4 THE EFFECT OF EXTRACTION METHODS ON BIOLOGICAL ACTIVITY

The extraction method is one of the key variables in determining the biological activity of plant extracts. The polarity of the solvent used, temperature, extraction time, plant-to-solvent ratio and drying conditions can all influence the chemical composition of the resulting extract.

Whilst polar solvents such as water, ethanol and methanol can be used for the extraction of phenolic compounds, solvents such as ethyl acetate may enable the recovery of compounds with different polarity characteristics. Consequently, it should not be expected that dandelion extracts prepared using different solvents will exhibit the same biological effect.

Nguyen et al. (2019) used an aqueous extract of dandelion root in their research into prostate cancer. The researchers extracted the plant material using water, filtered the resulting extract and, following lyophilisation, used it in their experiments. The effects of the extract obtained using this method on prostate cancer cells were evaluated in terms of dose and duration of treatment.

Kapancık (2024), on the other hand, analysed the chemical composition of dandelion extracts using gas chromatography–mass spectrometry (GC-MS) and assessed their antiproliferative effects in various cancer cell models.

When considered together, these studies show that extraction conditions determine not only the yield of the extract but also the type and quantity of the chemical compounds obtained. For this reason, the extraction method must be reported in detail in any research on dandelion relating to prostate cancer.

In particular, comparing extracts prepared using different solvents—such as water, ethanol and ethyl acetate—in the same prostate cancer cell models would be useful in elucidating the relationship between biological activity and chemical composition.

5 THE MOLECULAR DEVELOPMENT OF PROSTATE CANCER

The development of prostate cancer is associated with alterations in numerous molecular mechanisms that regulate cell growth and survival. In this process, androgen receptor signalling, growth factor receptors, intracellular protein kinases, DNA damage responses and regulators of apoptosis play key roles.

5.1 The androgen receptor signalling system

The androgen receptor is a protein belonging to the nuclear receptor family, which plays a key role in the development and maintenance of prostate cell function. Androgens such as testosterone and dihydrotestosterone bind to the receptor, altering its intracellular conformation and thereby regulating gene expression.

Abnormal activation of the androgen receptor signalling pathway in prostate cancer can promote the growth of tumour cells. In the advanced stages of the disease, alterations in the androgen receptor gene, overexpression of the receptor, or the activation of alternative signalling pathways may contribute to treatment resistance. Tortorella et al. (2023) have highlighted that the relationship between the androgen receptor and the PI3K/AKT signalling pathway plays a significant role in the development of prostate cancer and treatment resistance. The reciprocal interaction between these two systems is one of the mechanisms that explains why inhibiting a single molecular target does not always yield sufficient results.

5.2 The balance between cell proliferation and apoptosis

In normal cells, there is a controlled balance between proliferation and cell death. A disruption of this balance can contribute to tumour development by preventing the elimination of abnormal cells. Apoptosis is a mechanism of programmed cell death that ensures the controlled elimination of cells. In this process, proteins such as BAX and BCL-2 play a role in regulating the mitochondrial apoptotic pathway. Whilst BAX exhibits pro-apoptotic properties, BCL-2 functions as a protein that suppresses cell death. Caspases, on the other hand, are proteolytic enzymes that play a key role in the execution of the apoptotic process. Caspase-3, in particular, is one of the executor caspases responsible for the breakdown of cellular structures.

Experimental findings suggesting that dandelion extracts can induce apoptosis in prostate cancer cells highlight the importance of investigating these mechanisms. However, an increase in apoptosis alone does not indicate that a specific signalling protein has been suppressed. To elucidate the molecular mechanism, protein levels, enzyme activities and markers of cell death must be examined in conjunction.

5.3 Bıochemıcal Properties of Tyrosıne Kınases

Tyrosine kinases are enzymes capable of transferring a phosphate group, derived from an ATP molecule, to the tyrosine amino acid residues of target proteins. This process is known as protein phosphorylation. Phosphorylation can alter the structural properties of proteins, their interactions with other proteins, and their functions within the cell.

Tyrosine kinases are generally classified into two main groups: receptor tyrosine kinases and non-receptor tyrosine kinases. Whilst receptor tyrosine kinases are located on the cell membrane, non-receptor tyrosine kinases function within the cell. The activation of receptor tyrosine kinases usually begins with the binding of growth factors to the extracellular domain of the receptor. Ligand binding promotes receptor dimerisation and the activation of intracellular kinase domains. Subsequent autophosphorylation initiates intracellular signal transduction by facilitating the binding of various signalling proteins to the receptor. This mechanism plays a role in numerous biological processes, such as cell growth, metabolic regulation, differentiation and survival (Lemmon & Schlessinger, 2010).

An abnormal increase in tyrosine kinase activity in cancer cells can cause the cells to respond continuously to growth signals. Overexpression of the receptor, genetic alterations or an increase in ligand levels may all play a role in this process.

The importance of tyrosine kinases in cancer biology has led to the development of inhibitors that target these enzymes. However, for a molecule to be classified as a tyrosine kinase inhibitor, it must be experimentally demonstrated that it directly affects the activity of the relevant enzyme.

6 KEY TYROSINE KINASE RECEPTORS IN PROSTATE CANCER

6.1 Epidermal growth factor receptor (EGFR)

EGFR is one of the key members of the receptor tyrosine kinase family. Located on the cell membrane, the receptor undergoes dimerisation and autophosphorylation when it interacts with ligands such as epidermal growth factor.

Once activated, EGFR triggers various signalling proteins within the cell, thereby regulating mechanisms associated with cell proliferation and survival. In particular, the PI3K/AKT and RAS/RAF/MEK/ERK pathways play key roles in EGFR-mediated signal transduction.

The biological significance of EGFR in prostate cancer is assessed in terms of tumour cells' response to growth factors and their interaction with other signalling pathways. However, it should be noted that EGFR activity does not occur at the same level in all prostate cancer models.

In order to investigate the potential effects of dandelion extracts on EGFR activity, it is necessary to examine not only the total EGFR content but also the levels of phosphorylated EGFR. This will make it possible to distinguish between changes in receptor quantity and the receptor's activation status.

6.2 Insulin-like growth factor receptor (IGF-1R)

IGF-1R is a receptor tyrosine kinase involved in cell growth, metabolism and survival processes. Upon ligand binding, the receptor's intracellular kinase domain is activated, which can trigger various intracellular signalling mechanisms.

IGF-1R activation is associated with pathways such as PI3K/AKT and MAPK/ERK. These systems are important for the maintenance of cell proliferation and the regulation of responses to cellular stress conditions.

The evaluation of IGF-1R in prostate cancer research is useful for elucidating the effect of growth factor signalling on the biological behaviour of tumour cells. The effects of dandelion extracts on this receptor, however, require direct experimental investigation.

6.3 Fibroblast growth factor receptors (FGFR)

The FGFR family consists of receptor tyrosine kinases that play a role in processes such as cell proliferation, differentiation, tissue development and cell migration. The activation of these receptors triggers various intracellular signalling pathways.

FGFR-mediated signal transduction is linked to pathways such as RAS/MAPK and PI3K/AKT. Alterations in the FGFR system in cancer cells may influence tumour development and the response to treatment.

The relationship between dandelion extracts and FGFR activity has not yet been sufficiently elucidated. Consequently, the FGFR family is one of the receptor groups that could be evaluated in the investigation of the plant's potential molecular targets.

7 INTRACELLULAR SIGNALLING PATHWAYS ASSOCIATED WITH TYROSINE KINASES

7.1 The PI3K/AKT/mTOR signalling pathway

The PI3K/AKT/mTOR signalling system plays a key role in the regulation of cell growth, protein synthesis, metabolism and cell survival. Activation of this pathway is usually initiated by signals from receptors on the cell surface.

The activation of receptor tyrosine kinases can promote the recruitment of PI3K to the cell membrane and its activation. Activated PI3K converts phosphatidylinositol-4,5-bisphosphate (PIP2) into phosphatidylinositol-3,4,5-trisphosphate (PIP3). The accumulation of PIP3 contributes to the translocation of the AKT protein to the cell membrane and its phosphorylation via PDK1 and mTORC2.

Activated AKT regulates numerous target proteins within the cell. These proteins include molecules associated with the cell cycle, apoptosis and metabolic activities. As a result of AKT activity, the mTORC1 system may also be activated, thereby supporting cell growth through protein synthesis.

The PTEN protein contributes to the suppression of the PI3K/AKT pathway by facilitating the reconversion of PIP3 back to PIP2. Loss or dysfunction of PTEN in prostate cancer can lead to an uncontrolled increase in AKT activity.

Raith and colleagues (2023) reported that the reciprocal interaction between the androgen receptor and the PI3K/AKT/mTOR system plays a significant role in the development of prostate cancer and treatment resistance. This interaction demonstrates that the molecular structure of prostate cancer cannot be explained by a single signalling pathway.

Investigating the potential effects of dandelion extracts on the PI3K/AKT/mTOR pathway may help to explain the plant's antiproliferative properties from a molecular perspective. However, there is no definitive evidence that dandelion root extract directly inhibits this pathway.

7.2 The RAS/RAF/MEK/ERK signalling pathway

The MAPK/ERK signalling pathway plays a role in transmitting growth factor signals from outside the cell to the nucleus. This mechanism is usually initiated by the activation of receptor tyrosine kinases. The activated receptors trigger the activation of RAS proteins via adaptor proteins. RAS activation leads to a series of phosphorylation steps involving the RAF, MEK and ERK proteins. ERK activation can alter the function of various transcription factors within the cell nucleus. Consequently, cell proliferation, differentiation and responses to environmental stimuli are regulated. Abnormal activation of this pathway in cancer cells may contribute to the cells' continuous response to growth signals. Therefore, measuring p-ERK1/2 levels is one of the methods that can be used to assess the activation status of the MAPK/ERK system.

The effects of dandelion extracts on the MAPK/ERK system should be investigated, particularly with a view to elucidating the possible mechanisms involved in the suppression of cell proliferation. To this end, it is important to assess both total ERK and phosphorylated ERK levels together

7.3 SRC family tyrosine kinases

SRC family tyrosine kinases play a role in processes such as intracellular signalling, cell adhesion, migration and proliferation. These proteins can function in the transmission of signals from various receptors into the cell. Changes in the activity of SRC family members in cancer cells may be significant in terms of cell motility and interaction with surrounding tissues. Therefore, investigating the SRC signalling system may contribute to understanding the mechanisms of invasion and metastasis in prostate cancer.

Direct evidence regarding the effects of dandelion extracts on members of the SRC family is limited. Consequently, these proteins should be considered as potential targets for future mechanistic studies.

8 ANTICANCER EFFECTS OF DANDELION EXTRACTS

The biological properties of dandelion extracts have been investigated in various cancer cell models in recent years. The effects of extracts prepared from the plant's roots and above-ground parts on cell proliferation, apoptosis and cell invasion have been examined.

In their review evaluating the various biological activities of dandelion, Di Napoli and Zucchetti (2021) compiled experimental studies on the plant's antioxidant and anti-cancer properties. The researchers reported that dandelion had been investigated in various cancer cell models and that some extracts were capable of inhibiting cell proliferation. Sigstedt et al. (2008) evaluated the effects of dandelion aqueous extracts on the growth and invasion of breast and prostate cancer cells. This study is significant as it is one of the early experimental investigations examining the relationship between dandelion and prostate cancer. Kapancık (2024) investigated the chemical composition of dandelion extracts and their antiproliferative effects in A549 lung cancer and HT-29 colon cancer cell models. In the study, the chemical profile of the extracts was assessed using the GC-MS method, and gene expressions associated with cell proliferation and apoptosis were investigated.

These findings demonstrate that dandelion can exhibit biological activity in various cancer models. However, it would be incorrect to extrapolate the results obtained from different types of cancer directly to prostate cancer. The genetic structure, metabolic characteristics and signalling mechanisms of each cell model may differ.

9 DIRECT EXPERIMENTAL FINDINGS ON DANDELION AND PROSTATE CANCER

One of the key studies investigating the effects of dandelion on prostate cancer was conducted by Sigstedt et al. (2008). The study assessed the effects of the plant's aqueous extracts on the growth and invasion of breast and prostate cancer cells.

The significance of this study lies in the fact that it examined not only the general antioxidant properties of dandelion extracts but also their direct biological effects on cancer cells. The assessment of parameters such as cell growth and invasion has enabled the plant's anti-tumour potential to be investigated from various angles.

Nguyen et al. (2019) investigated the effects of dandelion root extract on prostate cancer in greater detail. The study utilised DU-145 and PC-3 prostate cancer cell lines. The researchers prepared the dandelion root extract using hot water and applied it to the cells at various concentrations.

The results indicated that dandelion root extract could induce time- and dose-dependent apoptosis in prostate cancer cells. Changes in cell death were assessed using Annexin V and propidium iodide staining. Furthermore, it was demonstrated that co-administration of the extract with certain chemotherapeutic agents could enhance the apoptotic response.

In another important phase of the study, experimental xenograft models established using human prostate cancer cells were evaluated. A reduction in experimental tumour burden was reported following oral administration of dandelion root extract.

These findings suggest that dandelion root extract has significant experimental potential in the context of prostate cancer research. However, it is not possible to interpret these results as evidence of clinical therapeutic efficacy. The research was conducted at the level of cell culture and animal models.

A key point to note in this study is that, although apoptosis was demonstrated, tyrosine kinase activity was not measured directly. Consequently, it cannot be concluded that dandelion root extract inhibits EGFR or any other receptor tyrosine kinase.

10 THE RELATIONSHIP BETWEEN OXIDATIVE STRESS, DNA DAMAGE AND APOPTOSIS

Oxidative stress arises as a result of an imbalance between the production of reactive oxygen species and the body's cellular antioxidant defence systems. Reactive oxygen species, such as the superoxide anion, the hydroxyl radical and hydrogen peroxide, are involved in various biochemical processes within cells (Phaniendra and Peryasamy, 2015).

Uncontrolled accumulation of reactive oxygen species can cause oxidative damage to DNA, protein and lipid structures. Oxidative changes occurring in DNA can promote the accumulation of mutations under conditions where cellular repair mechanisms are insufficient.

The role of oxidative stress in cancer cells is two-fold. Whilst, at certain levels, reactive oxygen species can promote proliferation by stimulating intracellular signalling mechanisms, an excessive oxidative burden can trigger apoptosis by increasing cellular damage.

The antioxidant properties of the phenolic compounds found in dandelion make this plant a suitable candidate for studies on oxidative stress. Yılmaz and Gözcü (2025) reported that dandelion root extract demonstrated antioxidant capacity in DPPH, ABTS and FRAP assays.

However, the results obtained from chemical antioxidant tests do not, on their own, demonstrate that the same effect occurs in cancer cells. To assess intracellular redox balance, cellular ROS measurements, glutathione levels, lipid peroxidation and indicators of oxidative DNA damage must be examined together.

The fact that dandelion extracts induce apoptosis in prostate cancer cells highlights the importance of investigating oxidative stress and cell death mechanisms in conjunction. In this context, it would be beneficial to examine markers of oxidative DNA damage, such as 8-OHdG, and molecular markers associated with apoptosis, such as BAX, BCL-2 and caspase-3.

11 THE POSSIBLE RELATIONSHIP BETWEEN DANDELION EXTRACTS AND TYROSINE KINASE ACTIVITY

Elucidating the molecular basis of the biological effects exerted by dandelion extracts on prostate cancer cells is a crucial step in assessing the anti-cancer potential of this plant. In particular, tyrosine kinase systems, which regulate cell proliferation and survival, are among the molecular targets that require investigation in this regard.

The plant's phenolic compounds, flavonoids and other secondary metabolites can interact via various biological mechanisms. However, the fact that a compound exhibits antioxidant or antiproliferative activity does not directly prove that it is a tyrosine kinase inhibitor.

Therefore, the effects of dandelion extracts on tyrosine kinase activity should be assessed at two distinct levels. The first level concerns potential changes in the phosphorylation status of intracellular signalling proteins. The second level involves the direct measurement of the catalytic activity of a specific tyrosine kinase enzyme.

11.1 Assessment in terms of EGFR phosphorylation

EGFR activation is associated with the phosphorylation of the receptor's intracellular tyrosine residues. Therefore, the assessment of p-EGFR levels is one of the methods that can be used to investigate receptor activation.

A reduction in p-EGFR levels in prostate cancer cells treated with dandelion extract may suggest that receptor activation has been suppressed. However, further investigation is required to determine whether this change stems directly from enzyme inhibition or from different regulatory mechanisms within the cell.

For this reason, it is necessary to measure both total EGFR and phosphorylated EGFR levels together, supported, where possible, by a direct EGFR kinase activity assay.

11.2 Potential interaction via the PI3K/AKT/mTOR pathway

Findings suggesting that dandelion root extract may increase apoptosis in prostate cancer cells necessitate further investigation into cellular survival mechanisms. The PI3K/AKT/mTOR system is an important area of molecular investigation in this regard.

A reduction in AKT activity may be associated with the suppression of cellular survival and increased susceptibility to apoptosis in certain cell models. Therefore, the analysis of p-AKT, total AKT, p-mTOR and associated downstream proteins may contribute to the evaluation of the potential effects of dandelion extracts.

However, the apoptotic response observed in the study by Nguyen et al. (2019) does not constitute direct evidence of PI3K/AKT/mTOR inhibition. Molecular-level validation is required to establish this relationship.

11.3 Potential interaction via the MAPK/ERK pathway

The MAPK/ERK system plays a key role in cell proliferation and differentiation. Increased ERK phosphorylation in cancer cells may contribute to the maintenance of growth signals.

Given the cell proliferation-inhibiting effects of dandelion extracts, the investigation of p-ERK1/2 levels is a suitable research approach. Any changes in p-ERK levels following extract administration may assist in the evaluation of signalling pathways associated with cell proliferation.

However, a decrease in p-ERK levels does not, in itself, directly imply tyrosine kinase inhibition. This change may result from differences at the receptor level, cellular stress or other regulatory mechanisms.

12 RESEARCH GAPS IN THE LITERATURE AND FUTURE PERSPECTIVES

Research conducted on dandelion has provided important insights into the plant's chemical composition and various biological activities. However, the number of studies aimed at explaining the molecular mechanisms in detail, specifically in relation to prostate cancer, is limited.

In particular, the lack of experimental studies evaluating the direct effects of dandelion extracts on tyrosine kinase activity represents a significant research gap. Whilst parameters such as apoptosis, cell viability and experimental tumour development have been assessed in existing prostate cancer research, it is necessary to directly measure the enzymatic activities of receptors such as EGFR, FGFR and IGF-1R. In future research, extracts should first be prepared from the root, leaf and flower parts of the dandelion using different solvents. The total phenolic and flavonoid contents of these extracts should be determined, and their chemical profiles should be characterised using analytical methods such as HPLC or LC-MS/MS.

In the second stage, cytotoxicity and cell viability analyses should be carried out using prostate cancer cell models. The evaluation of cell models such as DU-145 and PC-3, as well as LNCaP—an androgen receptor-positive prostate cancer model—could facilitate the comparison of cells with different molecular characteristics.

In the third stage, tyrosine kinase activity should be examined directly. To this end, enzyme activity assays targeting receptors such as EGFR, FGFR and IGF-1R may be utilised. In cell-based experiments, it would be appropriate to determine the levels of p-EGFR, p-AKT and p-ERK using the Western blot method.

The research should not be limited to a single protein. When cell viability, apoptosis, the cell cycle and signalling proteins are examined together, the biological effects of dandelion extracts can be explained more comprehensively.

In addition, it is important to evaluate the effects of the extract on normal prostate epithelial cells. Determining whether the cytotoxic effect observed in cancer cells also occurs in normal cells will assist in assessing potential selectivity.

13 DISCUSSION

Dandelion is one of the plants that has attracted attention in pharmacological research due to its various phytochemical constituents. The plant's phenolic acids, flavonoids, sesquiterpene lactones and triterpenes are being investigated for their diverse biological activities. The chemical properties of these compounds play a significant role in the evaluation of the antioxidant and other biological effects of the extracts.

With regard to the potential effects of dandelion on prostate cancer, the studies by Sigstedt et al. (2008) and Nguyen et al. (2019) are of particular importance. These studies demonstrate that different extracts of the plant can exert biological effects on prostate cancer cells. The use of experimental xenograft models alongside cell culture experiments in the study by Nguyen et al. broadens the scope of the findings.

However, when interpreting these results, the chemical composition of the extracts and the experimental conditions must be taken into account. It is not to be expected that an extract obtained from dandelion root using water would have the same compound composition as extracts prepared using different organic solvents. Consequently, it is incorrect to generalise the biological results obtained from one extract to all dandelion preparations.

The study conducted by Kapancık (2024) is significant in terms of the combined assessment of the chemical composition of dandelion extracts and their antiproliferative effects on various cancer cell models. The study on root extracts carried out by Yılmaz and Gözcü (2025), meanwhile, provides additional information regarding phenolic content and antioxidant capacity. These two studies complement one another in terms of investigating the relationship between the chemical composition of dandelion and its biological activity.

When assessed in terms of tyrosine kinases, it is evident that cell proliferation and survival in prostate cancer cannot be explained by the androgen receptor alone. In particular, the interaction between the PI3K/AKT/mTOR pathway and the androgen receptor is significant in terms of tumour development and treatment resistance (Raith et al., 2023; Tortorella et al., 2023).

These mechanisms provide suitable molecular targets for the investigation of dandelion extracts. However, it cannot be said that existing studies have demonstrated that dandelion extract directly inhibits EGFR, FGFR or any other tyrosine kinase. It is important to maintain a distinction between anti-cancer activity and enzymatic inhibition.

The fact that an extract reduces cell viability, increases apoptosis or lowers tumour burden may be the result of different molecular mechanisms. These effects may stem from changes in receptor activity, mitochondrial damage, the oxidative stress response or cell cycle regulators. Therefore, drawing conclusions regarding tyrosine kinase inhibition based solely on cell viability assays is not scientifically sufficient.

A key research gap highlighted in this review is that the effects of dandelion extracts on tyrosine kinase activity in prostate cancer cells have not been directly investigated. In particular, the combined assessment of phosphorylated receptor levels and enzymatic activities could help to elucidate this relationship.

Furthermore, as dandelion contains multiple chemical compounds, it is difficult to attribute the biological activity to a single molecule. Therefore, future research should evaluate fractions and purified compounds alongside crude extracts.

In conclusion, whilst dandelion possesses biologically active properties that are experimentally supported in the context of prostate cancer research, it represents a research area that remains insufficiently elucidated in terms of tyrosine kinase-related mechanisms. Studies conducted in this field could contribute to determining the plant's molecular effects and to a better understanding of the potential roles of naturally occurring compounds in cancer biology.

14 CONCLUSION

Dandelion (*Taraxacum officinale* F.H. Wigg.) is a plant source rich in phenolic compounds, flavonoids, sesquiterpene lactones, triterpenes and polysaccharides. The antioxidant and antiproliferative properties of extracts obtained from different parts of the plant have been investigated in various experimental studies.

In particular, studies reporting that dandelion root extract can induce apoptosis in prostate cancer cells and reduce tumour burden in experimental xenograft models highlight the plant's research potential in this field.

Tyrosine kinases and the associated EGFR, PI3K/AKT/mTOR and MAPK/ERK signalling pathways play significant roles in the molecular development of prostate cancer. Investigating whether these pathways are involved in the cellular responses induced by dandelion extracts may contribute to a molecular-level understanding of the plant's anti-cancer effects.

However, the current literature is insufficient to prove that dandelion extracts act as direct tyrosine kinase inhibitors in prostate cancer. Therefore, future research should combine direct enzyme activity assays, phosphorylation analyses, gene expression studies and cell-based experiments.

A detailed characterisation of the chemical composition of dandelion extracts and their evaluation in different prostate cancer cell models is important for identifying potential molecular targets. These studies must be supported in later stages by appropriate animal models and toxicity studies.

Overall, whilst dandelion is a natural resource worthy of investigation in the context of prostate cancer, its effects on tyrosine kinase activity remain an area of research that has yet to be fully elucidated. Consequently, a distinction must be made between the plant's anti-tumour potential—which is supported by current experimental findings—and its as yet unconfirmed molecular effects, and we must await the accumulation of scientific evidence regarding its clinical use.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declared no conflicts of interest with respect to the authorship and/or publication of this review.

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