The Discovery of Small Chemical Inhibitors for Cancer Treatment in Plants: A Review Article

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Abstract

The potential of compounds derived from plants as an alternative or complement to conventional cancer treatments is explored in this article. As powerful anticancer drugs, vinca alkaloids, taxanes, curcumin, and resveratrol bring about cell death, halt cell cycles, and obstruct angiogenesis. Discovering and optimising plant-derived small chemical inhibitors is made possible by advanced methods such as HTS and SAR analysis. Despite their lower toxicity and environmental benefits, challenges such as drug resistance, toxicity, and production complexities persist. The review emphasizes the need for continued research to enhance the efficacy, safety, and scalability of plant-based cancer treatments. Additionally, it highlights emerging trends in plant-based diets, noting their potential in reducing cancer risk while stressing the importance of further studies to assess their environmental impact and nutritional value.

1. Introduction

Cancer is a dangerous disease that affects people all over the world because it is marked by unchecked cell growth. Cancer is the second leading killer on a global scale (Aljurf et al., 2022). A great science and practical challenge that has global relevance is miniaturization of chemical inhibitors to treat cancer in plants. Secondary metabolites, which can be derived from plants, form the core of the research in this branch of study called phytochemical or plant-based drug discovery with the prospect of using such substances for developing new cancer treatments (Atanasov et al., 2021).

Plants have been known to be of therapeutic values and have been used in the agricultural practice, medicinal practice and conservation of the environment. In the field of medicine, plant synthetic inhibitors have been used as therapeutic agents, which exhibit diverse pharmacological activities. These medicines have a relaxing, disease preventing, antibacterial as well as pain relieving properties (Malviya & Malviya, 2023).

From an environmental point of view, plant secondary metabolites, such as chemical inhibitors, play roles in the defense of

ecosystem and the preservation of the biosphere. In this aspect, they function as chemical controls that guard plants from overgrazing by herbivores (Divekar et al., 2022).

1.1 Small chemical inhibitors

Small chemical inhibitors are molecules with low molecular mass which are originated from organic compounds that influence the biological processes with high specificity to targeted proteins or enzymes (Sun et al., 2021). They are important in the management of cancer since they can act to halt the ability of the cancer cells to multiply by interfering with biochemical activities. Small chemical inhibitor is found in plants, marine animals and flora, and also terrestrial microorganisms among others (Li & Kang, 2020). Sulforaphane, isothiocyanates, isoflavones, pomiferin, taxol analogs, vinca alkaloids, camptothecin derivatives and topotcan are example of tiny chemical inhibitors with anti-cancer phytochemicals found in plants. These substance are thus recommended for use in different types of cancer after passing through pre-clinical trials (Lu & Atala, 2016).

2. Historical Perspective

The World Health Organisation reports that traditional medicines derived from plants are used as primary healthcare by 80% of the world's population. Plants have adapted to environmental stresses by developing specific chemo-types with unique secondary structures over millions of years. Early drug development relied on these structures as their primary source of pharmaceuticals (Dias et al., 2012). The higher plants of tropical forests are used to source one-quarter of the present day drugs that are used in modern prescription (O'Hara et al., 1998). Several anticancer agents under current utilization in clinical trials were derived from plant sources as reported by Khazir et al., 2014. Some of the examples of anti-cancerous plant derived compound are Paclitaxel, curcumin, cannabinoids, strigolactones (Fridlender et al., 2015). Certain other plant derived compounds that have shown potential of being anticancer drugs are sulforaphane, isothiocyanates, isoflavones, pomiferin, taxol analogs, (lambda) alkaloids, camptothecin derivatives and topotecan (Jones, 2014).

3. Methods for Identifying Small Chemical Inhibitors in Plants

3.1 Phenotypic screening

One method for discovering tiny chemical inhibitors in plants is forward screening, sometimes called phenotypic screening. Using animal and plant models, this approach found new bioactive small compounds that might alter any phenotypic component and expose a biological process (Serrano et al., 2015). Novel therapeutic target agonists or antagonists are screened for in medicinal chemistry using target-oriented or reverse hit-to-lead approaches. Their goal is to find chemicals with target-specific binding capabilities (Kawasumi & Nghiem, 2007). Factors mediated by proteins, including enzymatic activity, interactions between proteins, and transcription factor binding, can form the basis of screening (Zabotina et al., 2008). Half of the drugs in development or already on the market are GPCRs, kinases, proteases, nuclear receptors, or ion channels; thus, target-based screenings are crucial in pharmaceutical modelling (Inglese et al., 2007). Since chemical instruments cannot probe nature to find new phenotypes or biological areas when limited to a few targets, basic research is hindered (Eggert,

2013). This necessitates investigating the effects of minute molecules on the phenotypic, or overall, characteristics of plants. Additionally, it might be utilised to discover ingredients that possess advantageous biological impacts, like medications that prevent cancer (Bloch et al., 2021).

3.2 Proteomics

Molecular methods that can be employed to compare protein levels in samples treated with small molecules to control samples include two-dimensional gel electrophoresis. This may make it easier in identifying the proteins that are directly affected by the chemicals as a result of post-translational modification (Lomenick et al., 2011).

3.3 High-throughput screening (HTS)

Consequently, HTS platforms can be applied to estimate the ability of practically unlimited libraries of small compounds to interact with certain targets or powerful physiological pathways of plants. These platforms often involve the use of automated equipments and sophisticated imaging techniques which shortens the screening process (Maji et al., 2019).

3.4 Structure-activity relationship (SAR) analysis

SAR analysis can be applied to optimise the structure of prospective small chemical inhibitors and its potency/selectivity/ADMET profile when the 'lead' has already been discovered. In this Darwinian process a series of compounds with different structures and formulae are designed and synthesized and only those compounds which possess the desired bioactivities are selected for further evolution (Lee et al., 2022).

4. Mechanisms of Action:

It also important to know how the plant or its compound affects cancer either positively or negatively. Indeed, the use of naturally derived compounds to prevent cancers is becoming more popular because traditional cancer treatments have had somewhat effective therapeutic results (Pan et al., 2013). Plant compounds can prevent the formation of blood vessels, which would be necessary to support the growth of an abnormal mass of tissue, in addition to stopping cell division and promoting the death of abnormal cells.

4.1 Apoptosis Induction

Thirty plant secondary metabolites have been identified and used in cancer chemotherapeutic trials, while over three thousand plant species are known to possess anticancer properties. Apoptotic processes, which may or may not be caspase dependent, are responsible for cell death in the majority of plant-based anticancer medications (Darwiche et al., 2007). Some other types of cell death that can be triggered by plant-based anticancer drugs include senescence-linked cell death, mitotic catastrophe, necrosis-like programmed cell death, and selective autophagy(Chan et al., 2015).

4.2 Cell Cycle Arrest

Cell growth and division are outcomes of the well-ordered universal processes which occur in the cell cycle. It well governed by many laws that either facilitate its growth or hinder it. The former include the cyclines, the cycline dependent kinases (CDKs), their target proteins, the Cdk inhibitors (CKI), the products of the tumor suppressor genes p53 and pRb (Zou & Lin, 2021). Most cell cycle regulatory genes are pro-proliferative and

can force cells that are not dividing to enter the cell division cycle hence being a causal factor in cancer. To promote cell cycle, they communicate with the basic components of the cell cycle machinery that leads to the entrance of the cell cycle. Everyone is looking forward to the chances of identifying anticancer medication therapy methods that will regulate cell cycle molecules. Cell cycle molecules that control the G1/S or G2/M cell transitions are upstream targets for these methods (Figel & Fenstermaker, 2018).

4.3 Anti-Angiogenic Effects

Tumour mass cannot surpass the oxygen diffusion limit without neo-angiogenesis, the formation of new capillaries from preexisting vasculature. For inflammatory diseases, tumours, and metastases, it plays a pivotal role (Sharma et al., 2001). According to Albini et al. (2012), angiogenesis can be used as a molecular target for the prevention and treatment of cancer using both synthetic and natural substances. To prevent the cancer from getting oxygen and nutrients, some phytochemicals prevent it from growing new blood vessels.

4.4 Immunomodulation:

Immunotherapy modulators derived from natural product of plants including polysaccharides, phenols, terpenoids, quinones and alkaloids are recently a new class of anti-cancer substance which are more effective to destroy cancer cells (Esmeeta et al., 2022). NK cells, macrophages, neutrophils, T cells, B cells, and dendritic cells are included in the basic immune cells that are specifically regulated by natural chemicals produced from plants. Plants synthesise and store a wide variety of anti-cancer chemicals, although in minute quantities. Besides they are incapable of being used in chemical synthesis in large quantity because of the complexity of their structures. Hence current approaches have focused on the synthesis of these natural products, NPs in heterologous systems to feed the market needs (Yang et al., 2021).

5. Plant-Derived Inhibitors

Worldwide, cancer is one of the leading causes of death and disability. As an example, 35,000 plant species are screened for anticancer qualities by the National Cancer Institute. There is consistent evidence that around 3,000 plant species have anticancer properties. For further information, see http://www.ars-grin.gov/duke/. Unfortunately, plant anticarcinogens aren't effective against all cancers. *Gynandropis pentaph, Anacardium occidentale, Asparagus racemosa, Boswellia serrata, Erthyrina suberosa, and Euphorbia hirta,* along with Freund virus leukaemia (Dhar et al., 1968). Cancer chemopreventive drugs help to halt the process of carcinogenesis; several of them are derived from natural sources. Most of the clinically valuable anticancer drugs including taxol, vinblastin, and vincristine derived from periwinkle plant, Camp tothecin derivates such as topotecan, irinotecan and etoposide derived from epipodophyllotoxin. Several novel prospective compounds are in clinical trials due to their anticancer activities based on the selectivity towards cancer associated molecular targets: flavopiridol and roscovitine, combretastatinA4- phosphate, betulinic acid and silvestrol are in clinical or pre-clinical stages(Shoeb, 2006) .

5.1 Vinca Alkaloids

The first anticancer drugs produced from plants to be used in clinical practice are

vincristine and vinblastine (Dehelean et al., 2021). Brogan published a study in 2010. Vinca alkaloids are found in Madagascar periwinkle. The pink periwinkle plant, Catharanthus roseus G. Don, is a source of either naturally occurring or partially treated nitrogenus bases (Kufe et al., 2013). According to Ferrares et al. (2008), Barrales-Cureño (2015), and Kumar et al. (2022), herbal medicine makes use of more than 150 indole alkaloids, which is out of 345 bioactive phytochemicals, as anti-cancer medications.

Different parts of C. roseus plants have been reported to have cancer, gastrointestinal, diabetes, liver, kidney, and cardiovascular disease treatment using folkloric Ayurvedic medicine all over the world

At present, it is possible to isolate individual indole alkaloids from C. roseus which are available in different brands including Velban, Oncovin and Vinflunine. Such products are used in treatment of ailments of disease and syndromes such as Hodgkin's disease, Lymphosarcoma, Neuroblastoma, Carcinoma of the breast (Kumar et al., 2022).

5.2 Taxanes

Chemotherapy medications belonging to the Taxol family include taxanes, Jevtana, and Taxotere. Similar to how these drugs shed light on many cancers, they also treat them. In cancer cells, taxanes trigger cell division by destroying microtubule bundles. The cancer cells are killed off because this disruption stops them from dividing and expanding. In the past, paclitaxel (Taxol) and other cancer chemotherapy medications were manufactured from the trunks of the Pacific yew tree (Taxus brevifolia) (Kingston & Cassera, 2022). In the early 1970s, the first taxane to demonstrate anticancer effect on rodents was paclitaxel, a compound derived from the Pacific yew tree.

5.3 Cannabinoids

Marijuana, originating from Central Asia, is cultivated globally and contains over 100 cannabinoids, the most notable being THC and CBD. These cannabinoids, primarily found in the female flowers of the cannabis plant, are part of a complex mixture of around 490 compounds, including terpenes, flavonoids, and alkaloids (Adams & Martin, 1996; Brenneisen, 2007). Terpenes, which have synergistic effects with cannabinoids, contribute to the plant's bioactivity (McPartland & Russo, 2001; Russo & McPartland, 2003). According to O'Reilly et al. (2022), cannabis has the ability to impede tumour growth and spread, reduce proliferation, and trigger cancer cell death. Dronabinol and nabilone, two synthetic cannabis drugs approved by the FDA, alleviate nausea and vomiting caused by chemotherapy (Board, 2012). These medications are part of the medicinal marijuana list and are commonly recommended by oncologists for cancer treatment side effects (Sexton et al., 2021).

5.4 Curcumin

A well-liked spice, curcumin (Curcuma longa), is made from the turmeric root. The chemical name contains the following elements: The compound is 1,7-bis [4, hydroxy; 3, methoxyphenyl] hepta 1,6 diene 3,5 dione (1E, 6E). It has a long history of use in the treatment of inflammation, skin wounds, tumours, and infections in the Indian subcontinent and Southeast Asia. The anti-cancer chemopreventive effects of

curcumin are extensive, according to animal research. One reason curcumin is effective against cancer is that it stops nearly all cancer cells from dividing and activating. Factors that regulate transcription include NF-B, AP-1, and Egr-1; chemokines, cell adhesion molecules, NOS, MMP-9, uPA, TNF, and NF-B; and growth factor receptors and cyclin D1 synthesis are suppressed. (like EG (Palve & Nayak, 2012). According to López-Lázaro (2008), curcumin can be safely administered using pharmaceutical means. Researchers have looked into the anticancer effects of several curcumin molecules (Mbese et al., 2019).

5.5 Resveratrol

According to Sharifi-Rad et al. (2022) and Jang et al. (1997), resveratrol (Res) is a chemical that can enhance carcinogenesis at all stages. It is found in red grapes, berries, and peanuts. According to Venkatadri et al. (2016) and Ma et al. (2019), Res can benefit chemotherapy by promoting cancer cell death and modulating microRNAs (miRs), especially onco suppressor miRs. Additionally, it lowers DNA damage, oxidative stress, and metastasis through influencing the EGFR, mTOR/AKT, and JAK/STAT pathways (Akhtar et al., 2020).

Resveratrol's effect on Nrf2, a transcription factor, is debated. While it may activate antioxidant defenses and offer chemoprevention, Nrf2 activation can also promote cancer cell survival and proliferation, highlighting its dual role in cancer therapy (Alavi et al., 2021; Wu et al., 2019). Furthermore, resveratrol induces cancer cell cycle arrest, particularly in the G0/G1 phase, through caspase-dependent and noncaspase pathways (Sofi et al., 2022).

Though widely available as a dietary supplement, particularly derived from Japanese knotweed (Barber et al., 2022), resveratrol is not FDA-regulated and lacks approval as a cancer treatment. Its clinical application is still under investigation (Khattar et al., 2022).

5.6 Camptothecin

Camptothecin (CPT), first isolated from *Camptotheca acuminata* in the 1950s, has been the basis for numerous derivatives, particularly for cancer therapy. Two first-generation CPT analogs, irinotecan (CPT-11) and topotecan (TPT), were FDA-approved in 1996 for treating colorectal cancer (CPT-11) and ovarian, cervical, and small-cell lung cancers (TPT) (de Lucas Chazin et al., 2014; Ling et al., 2015). CPT and its derivatives target topoisomerase I (Top1), interfering with DNA replication and transcription, leading to cancer cell apoptosis (Li et al., 2017). Challenges such as solubility and toxicity have prompted the development of nanoparticle-based formulations to improve efficacy (Liu et al., 2015). Hydroxycamptothecin (HCPT) was China's first independently studied derivative in the 1970s, showing promise in clinical trials (Liu et al., 2015). Recent analogs like ZBH-01 and ZBH-ZM-06 demonstrate enhanced antitumor activity, with ongoing trials for ovarian and colon cancer treatments (Hu et al., 2018; Li et al., 2023; Wu et al., 2018).

5.7 Etoposide

Podophyllum peltatum and Podophyllum emodi, members of the Berberidaceae family, are sources of the non-alkaloid toxic lignan epipodophyllotoxin, from which Etoposide (VP-16) is derived. First synthesized in 1966 and FDA-approved in 1983, Etoposide remains an essential chemotherapy drug, used to treat various

cancers including testicular carcinoma, small cell lung carcinoma, leukemia, breast cancer, and brain tumors (Hande, 1998; Noronha et al., 2020; Alsdorf et al., 2019). Despite its efficacy, developing compounds like Etoposide remains a challenge due to difficulties in sourcing podophyllotoxin from the Himalayan mayapple (Meresse et al., 2004). Recent research suggests Nicotiana benthamiana could be engineered to produce Etoposide's precursor, offering a more sustainable source (Davey, 2020).

Etoposide works by blocking the G2/M phase of the cell cycle, although quercetin can counter this effect, restoring normal progression and regulating proteins such as cyclin B1 and p53 (Stuart et al., 2012). Studies also suggest its potential role in MLL gene rearrangements, linked to leukemia (Felix et al., 2006). Efforts to improve Etoposide's efficacy and reduce side effects include using etoposide phosphate (EP), which showed enhanced cancer control with fewer side effects in animal models (Kiran et al., 2018).

5.8 Silver nanoparticles (AgNPs)

Metal nanoparticles, including gold, silver, zinc, and others, can be synthesised by green nanotechnology (Makarov et al., 2014). Antimicrobial, anticancer, anti-parasitic, antidiabetic, antioxidant, drug transport, bio-molecular detection and diagnostic, food processing, and agricultural applications are just a few of the many biomedical uses for silver nanoparticles (AgNPs). The synthesis of AgNPs using plant extracts was the focus of this investigation. Cleome viscosa L., a member of the castellidaceae family, is a common weed in tropical areas across the globe.Paval and colleagues (2009) stated that... According to Nadkarni and Nadkarni (1982), traditional medicine makes use of tick-weed, wild mustard, and entire plants. According to Devi et al. (2013), the fruit extract of C. viscosa included flavonoids, reduced glutathione, ascorbic acid, peroxidase, polyphenol oxidase, superoxide dismutase, glutathione-S-transferase, and ascorbic acid. Using reducing and capping agents, they contributed to the synthesis of silver nanoparticles.

Phenols, flavonoids, alkaloids, and terpenoids are some of the bioactive secondary metabolites found in medicinal plants. These are used to treat a variety of illnesses, including infectious ones. in 2012 Theodore and Philip C. The biological potential of green silver nanoparticle synthesis is high.

5.9 Isothiocyanates

Isothiocyanates (ITCs), derived from cruciferous vegetables through myrosinase-catalyzed hydrolysis of glucosinolates, show chemotherapeutic potential (Andernach et al., 2023). Animal studies indicate that ITCs prevent cancer formation when administered prior to exposure to chemical carcinogens (Saylan & Cebeci, 2023). Besides affecting carcinogen metabolism and cancer cell survival, ITCs inhibit angiogenesis in both cell cultures and animal models, a key mechanism in their chemopreventive effects (Fofaria et al., 2015). Angiogenesis, first targeted for solid tumor therapies in 1972, has led to FDA-approved drugs like sorafenib and bevacizumab, with ongoing research exploring resistance and drug interactions.

5.10 Oridonin

The diterpenoid compound oridonin is derived from a number of species of Isodon that are used as medicinal herbs in traditional Chinese and Japanese medicine (Ding et al., 2016). Oridonin primarily

comes from the plant Isodon rubescens, which is also known as Rabdosia rubescens or Donglingcao. This medicinal herb contains oridonin (Wiart, 2012). The anticancer effects of ori are substantial, according to research by Tan et al. (2011). Theoretically, Ori may target many cancers by modifying signalling pathways including intracellular ROS, Bcl-2/Bax, NF-kB, p53/p21, MAPK, PI3K, microRNAs, and FASN (Pi et al., 2017). Oridonin blockades the nucleolin protein, which promotes the growth of cancer cells. According to Vasaturo et al. (2018), it protects Nucleolin against thermal denaturation and targets cancer cells. Our research shows that oridonin makes NSCLC cells more resistant to radiation-induced growth inhibition and clonogenic cell death. Because of its properties, the plant will help radiation treatment for cancer. Last year, Park and colleagues published... Researchers found that oridonin effectively fought osteosarcoma. Stimulates the PPAR-γ pathway while suppressing the Nrf2 pathway, leading to the inhibition and eventual death of cancer cells. Research has demonstrated that oridonin can combat breast cancer, leukaemia, and lymphoma through inducing cell death (Lu et al., 2018). The concentration determines its impact on cell survival. With its ability to promote autophagy, cell cycle arrest, and death, Ori is also anti-angiogenic because it inhibits the creation of capillary-like networks. Ori exhibited anti-tumor and anti-metastasis properties, which were attributed mostly to Claudins 1, 4, and 7, according to Tian and colleagues.2007 (in a study by Tian and colleagues).

5.11 Amygdalin

Amygdalin, commonly referred to as vitamin B17 or laetrile (a synthetic form), is a plant-derived compound found in apricot pits, raw nuts, and some beans. It has been controversially explored as a cancer treatment. Proponents argue that its action involves releasing cyanide, which targets and kills diseased cells, including cancer cells (Integrative, 2013; Campos et al., in press). Amygdalin has been used in cancer treatments in countries like Germany, Italy, and Japan (Chang et al., 2005), but no conclusive scientific evidence supports its efficacy. Clinical trials have been limited, and amygdalin was banned by the FDA in the 1980s due to its toxic effects, which include cyanide poisoning, nerve damage, and even death (Jasar et al., 2008). Recent research has suggested that amygdalin might have cytotoxic effects on various cancer cells, including lung, breast, and prostate cancers, by inducing apoptosis and affecting proteins involved in cell death (Spanoudaki et al., 2023; Lehmane et al., 2023). However, its safety and effectiveness remain under debate, and its use in cancer therapy is still not widely accepted (He et al., 2020).

6. Advantages of Plant-Based Treatments

Low-grade systemic inflammation is reduced and health is improved, including cancer prevention, by following a plant-based diet. Eating nutritious plant-based meals has been found to lower the incidence of breast and prostate cancer (Shah et al., 2022; Anyene, 2021). An increased plant-based diet was associated with a 52% lower risk of disease progression and a 53% lower likelihood of recurrence in men with prostate cancer, according to a recent study (Ligibel et al., 2022). A PubMed study found that the risk of deadly prostate cancer was reduced in men who consumed more plant-based foods (Loeb et al., 2022).

Plant-derived compounds like berberine, curcumin, and resveratrol show anticancer properties by targeting factors involved in tumor progression and metastasis (Alibakhshi et al., 2023). These natural compounds are less toxic and cause fewer side effects than traditional chemotherapeutic agents (Talib et al., 2020). Plant-based therapies are also more cost-effective and accessible, potentially leading to more targeted and personalized cancer treatments (Malviya & Malviya, 2023). However, while plant-based diets and remedies show promise, further studies are needed to confirm their efficacy in cancer treatment in humans and to ensure precise food composition for optimal anticancer benefits.

7. Limitations of Conventional Methods

Conventional cancer treatment methods have several limitations, including:

Some synthetic drugs can cause significant side effects and toxicity, limiting their long-term use (Chakraborty & Rahman, 2012).Plant-based treatments often have fewer adverse effects, making them safer options in certain cases (Mondal et al., 2014).The existence of drug-resistant pathogens, and cancer is a concern in general medicine. Natural products offer a rich source to develop new strategies to overcome the issue of drug resistance. Traditional processing of drugs can lead to production of chemicals wastes during production and it is clear that it has implications to the environment. Natural reme-, dies have the advantages of being more cost effective and kinder to the environment. Standard chemotherapy is non-selective, and consequently normal, rapidly dividing cells are affected. Certain plant based therapies can be made to act only on malignant cells and hence spare the normal cells. (Chidambaram et al., 2011).Limited Efficacy: Some of the challenges associated with conventional treatments include the heterogeneity of tumors, slow penetration of tissue by anticancer drugs among others. These deficits can be overcome with plant-based treatments in order to enhance the efficacy of therapies. Most conventional chemotherapy is non selective and can harm healthy cells in the body and this results to many side effects. Plant based treatments can be made to be more specific with less side effects on the normal cells. (Tannock, 1998).

It is imperative to deal with these limitations in order to enhance the results of cancer therapy. The treatments from plants can be helpful as an adjunct or as a stand-alone from the traditional treatments, and there is a need to carry further researches to reach the optimum use of these products.

8. Current State of Research

Botany as a research area has continued to experience development in the past few years because of the continued discovery of the pharmacological effects of plant products. The following is a review of the current state of plant-based research, drawing from top publications in the field:The following is a review of the current state of plant-based research, drawing from top publications in the field:

- Using 40 cases or cohort cases of diet-and weight-related studies published before May 2020, a systematic review was conducted to look at the impact of dietary changes on health. Another health benefit the review pointed out was that plant based diets are in a position to

actually lower risk factors to the contracting of diseases. (Clem & Barthel, 2021).

- Another review published in 2021 was lay out on the scientific approach on design of healthy and sustainable plant-based foods. Of course, it briefly described the current state in terms of the scientific analysis of plant-based foods and revealed gaps that require further study. In the review, chemical and physical attributes of the plant ingredients, processing operations involved in converting the plant ingredients into most of foods, and the science that goes with the development of meat, egg and milk analogs were covered. It also discussed such obstacles based on consumers and raised intent on having a better understanding of consumers in order to prompt the take-up of plant-based foods. (McClements & Grossmann, 2021).
- A systematic review that was conducted in 2023 addressed possible advantages and challenges of the transition to plant-based diets. The review spoke of some of the positive effects of taking plant products like the one relating to the prevention of the chronic diseases. It also gave proper consideration to environmental impacts of plant-based diets which is lower in terms of greenhouse gas emission, land use and freshwater use than animal-based diets. The review underscored the necessity of political recommendations for the health professionals with an aim of safe and appropriate government of plant-expression diet (Craig et al., 2021).
- Investigations into plant-based meats have also been carried out though these products have recently received public interest. The literature review published in 2022 tries to condense the knowledge about the meat-protein to support researchers who restructure plant meat. In the review, the author talked about the chemical and present day formation and advancement of plant-based meat analogues and some of the difficulties connected with its production. (Ahmad et al., 2022).
- Cooperation between botanists, pharmacologists, chemists, and clinicians has expanded plant category knowledge. This working collaboration between the pharmacology and agriculture disciplines has given insights on the mode of action of plant-derived compound. Further studies on plant based remedies have gone global, with research on different plant species of different world regions. Such collaborations have led to the sharing of information and material, biome, resources between countries (Clem & Barthel, 2021).

9. Challenges and Future Directions

Plant-based research has made significant strides in the last decade, yet several challenges remain. One major issue is the textural quality, flavor, and juiciness of plant-based meat alternatives, which need improvements to meet the nutritional needs of flexitarian and vegetarian consumers, particularly in terms of vitamin D and other

key nutrients (Alcorta et al., 2021). Another challenge is the standardization of plant-derived compounds, as congeners in plant extracts complicate the determination of fixed therapeutic doses, necessitating standardized protocols for consistent research results (McClements & Grossmann, 2021).

While many plant-based compounds have therapeutic properties, their precise biological mechanisms are poorly understood, requiring further investigation (Krzywonos & Piwowar-Sulej, 2022). Additionally, extended risk evaluations and studies on pharmacological interactions are needed to ensure the safety of plant-based treatments (Liu et al., 2023). More research is also required to evaluate the nutritional value of plant-based diets and to provide guidance for healthcare professionals on safely incorporating them into daily diets (Menta et al., 2022). Despite being considered environmentally friendly, the environmental impact of plant-based agriculture still lacks sufficient data, calling for further study (Loh et al., 2022).

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