

Bell Peppers (*Capsicum annuum*): Treasure Mine for Bio-active Exploration and Its Uses in Functional Food, Nanoparticle Synthesis and Therapeutic Applications

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Abstract. Capsicum (*Capsicum annuum*), a prominent vegetable of the Solanaceae family, exhibits a spectrum of colors—from green-to-red reflecting its stage of ripening and pigment composition. It is a rich source of vitamins (C, E, A) and bioactive compounds, capsaicinoids, which contribute to its characteristic pungency and confer diverse health-promoting properties. Beyond its traditional use as a vegetable, natural colorant, and folk remedy, recent studies have explored its multifunctional applications in food and biomedical sciences. Capsicum-derived bioactive compounds have demonstrated anti-diabetic, anti-inflammatory, antimicrobial, and antioxidant activities. At the same time, its potential in nanoparticle synthesis has opened new avenues for targeted therapeutic delivery and enhanced bio-efficacy. The incorporation of capsicum in edible coatings and food fortification strategies has shown promise in improving the shelf life, sensory attributes, and microbial safety of processed foods. The impact of various processing methods—including thermal treatments, drying, and extraction—on its phytochemical profile and functional properties has been systematically evaluated, emphasising the importance of optimised processing for maximal bioactivity retention. This review consolidates current knowledge on the nutritional and bioactive potential of capsicum, its applications, and underscores its emerging significance as a multifunctional vegetable with wide-ranging implications in food science, medicine, and public health.

Keywords: bioactive compounds; functional food; fortification; medicinal property; nanoparticle synthesis.

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1 Introduction

Capsicum (*Capsicum annuum* L.) is a globally significant vegetable with substantial economic and nutritional importance. This round-shaped fruit exhibits a range of colors—

including green, yellow, orange, and red—depending on its developmental stage and pigment biosynthesis capacity. Microscopically, the epidermal cells of capsicum are polygonal, featuring both straight and curved anticlinal walls. Commonly referred to as sweet pepper or Shimla mirch, it thrives in daytime temperatures of 20–30 °C and requires 18–20 °C at night, along with 50–60 % relative humidity for optimal growth. Archaeological findings indicate that capsicum fruits have been utilized since ancient times for both medicinal purposes and as natural colorants. Taxonomically, Capsicum is classified within the Solanaceae family, Solanoideae subfamily, genus *Capsicum*, and species *annuum*. It is widely cultivated in tropical and subtropical regions worldwide, including India. Capsicum fruits are a rich source of essential micronutrients, particularly vitamins A, C, and E. Recent studies have highlighted that bioactive compounds extracted from capsicum exhibit significant pharmacological properties, including anti-diabetic, antimicrobial, and anti-inflammatory activities, underscoring its potential as a functional food and therapeutic agent.

The color of bell peppers is a critical quality attribute that significantly affects consumer preference and marketability. Green coloration is primarily due to chlorophyll and associated pigments within the chloroplasts. Yellow to orange hues result from the accumulation of carotenoids such as β -cryptoxanthin, α -carotene, β -carotene, lutein, and zeaxanthin. The characteristic red color of mature peppers is attributed to carotenoid pigments, including capsanthin, capsanthin 5,6-epoxide, and capsorubin. Variations in the concentration and composition of these pigments, influenced by genetic and environmental factors, underlie the diverse coloration observed among bell pepper cultivars [1]. Capsicum contains a group of alkaloids known as capsaicinoids, which are primarily responsible for its characteristic pungency. To date, twelve major capsaicinoid compounds have been identified, with dihydrocapsaicin and capsaicin contributing approximately 85–90% of the total pungency. Recent studies indicate that capsaicin is predominantly localized in the vacuole-like epidermal cells of the placental tissue within the pericarp, whereas the seeds generally contain minimal amounts. The highest concentrations are observed in the ovary and the basal portion of the fruit. Based on pungency levels, capsicum varieties are categorized into five classes: non-spicy, mildly spicy, moderately spicy, highly spicy, and extremely spicy. Sensory evaluation of both fresh and powdered bell peppers is commonly performed using the Scoville Heat Unit (SHU) and Gillette scales to quantify their pungency. Extensive research has been done to discover important genes that regulate fruit output and quality characteristics in Capsicum. Plant height, fruit weight, fruit form, pericarp thickness, and maturity have all been shown to be influenced by two capsanthin genes, capsorubin synthase and phytoene synthase. Capsaicinoids are high-value compounds which are derivatives of phenylpropanoid compounds, and they have antibiotic potency, hence it decrease cholesterol levels in the blood. For human consumption, peppers are rich source of antioxidants and vitamins, like carotenoids, phenols, vitamin C, and folates. The nutrient components of peppers are mainly dependent on the variety and their stages of maturity.

Bell peppers have been extensively studied due to their significant contribution to taste, color, and flavor in diverse food systems. However, comprehensive reviews addressing their application in food fortification, potential in nanoparticle synthesis, the properties of capsicum-derived nanoparticles, and the impact of various processing techniques on their phytochemical composition remain limited. This study provides an integrated overview of the bioactive potential and medicinal properties of bell peppers, their role in nanoparticle synthesis, strategies for food fortification, and the effects of different processing methods on their nutritional and functional properties.

2 Botanical Description

The subtropical perennial plant *Capsicum annuum* is native to Mexican states, America, and the West Indies. It belongs to the nightshade family, Solanaceae. Fruit morphologies are used to classify *Capsicum annuum* types and cultivars. After fertilisation, the gynoecium develops and differentiates into fruits. They're the result of late morphological and structural changes in the carpels.

Crops are sown in the springtime and collected when the beans are lustrous and mature in the summer and autumn. The solitary blooms are off-white (occasionally purple) in hue, with a thickly branching stem that can reach 60 cm (24 in) in height. Peppers are fruits that can be green, yellow, orange, or red when ripe. While *C. annuum* may grow in most frost-free areas, it thrives best in hot, dry conditions.

Microscopic observation is a prime tool to pick out and classify spices, so it shows morphological changes at various ripening stages. Scholars have analysed by SEM (Scanning Electronic Microscopy) and light microscope four bell pepper species (*Capsicum frutescens*, *Capsicum annuum*, *Capsicum baccatum*, and *Capsicum chinense*) [1]. Phenotypic differences in growth, seed colour, and shape were observed, whereas molecular variability and morphology were not showed in anatomical features.

3 Bioactive Composition of Bell Pepper

Bell peppers have different color variants, like green, red, yellow, and orange. The sweet bell pepper is mainly produced in the north-eastern part of India. This crop needs moderate heat (20-30°C) for growing with a humidity of 50–60%.

Bioactive compounds are “inherent non-nutrient constituents of food plants with anticipated health-promoting/beneficial and/or toxic effects when ingested”. Bioactive molecules of bell peppers are the products of secondary metabolism. Phytochemicals isolated from bell pepper are known as natural bioactive substances, and they have long been important as cutting-edge therapeutic agents. They have numerous therapeutic properties and a major direct and indirect influence on human health. Bioactive substances are essential to a healthy diet. Capsicum is a vegetable rich in bioactive components, which include polyphenols, flavonoids, carotenoids, a complex mixture of essential oils, cinnamon acid, and capsaicinoids. Ascorbic acid acts as a natural bioactive molecule that can fight against a variety of diseases, including cancer, hypertension, and neurodegenerative diseases. Vitamin C is sensitive to heat, light, and oxygen. Therefore, it acts as an indication of nutrient loss during heat-related processes. The carotenoids are one class of bioactive substances that contribute to the colour of bell peppers. The carotenoids α -carotene, β -carotene, capsanthin, violaxanthin, capsorubin, and capsanthin 5, 6-epoxide are among the most significant ones found in capsicum. Capsicum seeds, peels, and stems also contain a rich source of phytochemical compounds. These chemicals are antioxidants that can help the human body reduce hazardous oxidation reactions. Capsicum use can help prevent cancer, neurological disorders, and cardiovascular disease, all of which are linked to free radical oxidation reactions. All of these bioactive substances have a significant amount of potential for usage in the pharmaceutical and food sector.

It represents a reservoir of structurally diverse phytochemicals with broad biological activities. The most characteristic constituents, capsaicinoids such as capsaicin and dihydrocapsaicin, are alkaloids that confer pungency and exhibit analgesic, thermogenic, antimicrobial, and antineoplastic effects through interactions with molecular targets, including Transient Receptor Potential Vanilloid 1 (TRPV1) receptors. Carotenoids, notably capsanthin, capsorubin, and β -carotene, contribute to the distinctive pigmentation of ripe fruits and function as potent antioxidants with documented benefits for visual health and oxidative stress reduction. In addition, flavonoids (e.g., quercetin, luteolin) and phenolic acids (e.g., caffeic acid, ferulic acid) are implicated in anti-inflammatory, cardioprotective, and radical-quenching mechanisms that support metabolic homeostasis. High levels of ascorbic acid and tocopherols further strengthen the fruit's immunomodulatory and cytoprotective potential. Taken together, these metabolites highlight capsicum as a functional food and a valuable natural source for applications in nutraceutical, pharmaceutical, and cosmeceutical formulations.

3.1 Phenols and flavonoids

Capsicum gives potential health benefits by scavenging the free radicals formed in the human body. Phenolic content changes during the stage of maturation, which affects the composition and antioxidant activity. Sources of bioactive compounds are listed in Table 1. The glycosides and aglycones of myricetin, apigenin, luteolin, quercetin, and kaempferol are flavonoids found in most capsicums. The amount of quercetin and luteolin in the flavonoid fraction was measured during acidic hydrolysis. Researchers have performed a more extensive examination of pepper phenolics, identifying 10 bioactive compounds in bell pepper, of which three were developed on a novel structure: capsioside A, capsioside B, and capsianoside VII. These compounds influence hemostatic regulation when incorporated into the diet as well as participate in metabolic processes to boost immunity regularly. The phenolic compound has therapeutic activity; it cannot be produced in the human body, so it has been taken through the diet.

During ripening, the concentration of bioactive elements and the overall phenolic content of bell pepper fruits were examined by [2]. They came to the conclusion that the Folin-Ciocalteu method was employed to determine the total polyphenols in *C. annuum*, were comparable in the beginning stages of maturation (75.9 and 72.8 mg/g in green fruits); and lowered in the end stages of ripening (42.3 mg/g in red pepper), whereas maximum bioactive compounds were found at the intermediate state of maturity.

The polyphenol concentration of the capsicum compound is analysed by the Folin-Ciocalteu method. Researchers have reported that phenolic concentrations increase as per their maturation stages. In the first stages of maturation, the concentration of the phenolic compound is 76 mg/g, and in the last, it is 43.3 mg/g. Main phenolic compounds are myricetin (658 μ g/g), catechol (279 μ g/g), caffeic acid (107.03 μ g/g), ellagic acid (106 μ g/g) and gallic acid (89 μ g/g) present in green capsicum in different concentrations while red bell peppers are the rich source of chlorogenic acid (221 μ g/g), benzoic acid (111 μ g/g), myricetin (245 μ g/g) and ellagic acid (172 μ g/g) were present. Moreover, researchers reported that the yellow bell pepper enriched with ellagic acid (144 μ g/g), benzoic acid (174.5 μ g/g), pyrogallol (2175 μ g/g), myricetin (151 μ g/g), and catechol (225 μ g/g). Except for all, orange pepper has a sufficient amount of gallic acid (900 μ g/g), resveratrol (89 μ g/g), myricetin (100 μ g/g), ferulic acid (13.45 μ g/g), and caffeic acid (38 μ g/g) were found. These compounds all have high potential antioxidant activity against ROS.

Similar to polyphenol, the concentration of flavonoid content also varies depending on the ripening stages of fruits and the colour of the pepper. Flavonoid concentration varies from 2.1 mg of QE/g of capsicum to 4.1 mg of QE/g. The main flavonoid components with their concentration in green pepper are quercetin (394 µg/g), hesperidin (1065 µg/g), naringin (275 µg/g) and catechin (295 µg/g) addition, red pepper contains a sufficient amount of catechin (793 µg/g), rutin (290 µg/g), luteolin (413 µg/g), hesperidin (1513 µg/g), and quercetin (241 µg/g) were present (Kaur & Kaur, 2021). Furthermore, yellow peppers contain a rich amount of hesperidin (212 µg/g), catechin (745 µg/g), luteolin (95 µg/g), and quercetin (102 µg/g). On the other hand, orange bell pepper contains the amount of quercetin (38.04 µg/g), catechin (56 µg/g), and luteolin (57 µg/g).

3.2 Carotenoids

Pepper contains a rich source of carotenoids, which are lipophilic in nature, as shown in Table 1. It is a native source of colour and is also used as a food colorant and food additive. Carotenoids are the isoprenoid compounds that are responsible for the exotic colour of pepper. It is essential for wellness of health due to its nutraceutical properties and plays a vital function in preventing ROS formation in the human body during metabolic activity. Carotenoids have uses in the food, nutraceutical, and medicinal sectors. Algae and microbes also have these pigments. It is an isoprenoid compound having more than 700 structures, most of which are the coloured structures, which have the linear tetraterpene phytane (C₄₀).

The modification in the backbone of the linear structure is responsible for diversity, for example, simple carotenoid to xanthophyll. According to their biological importance, they were divided into two categories such as primary and secondary carotenoids. Primary carotenoids participate in photosynthesis directly (β -carotenoids, zeaxanthin, and lutein), and secondary carotenoid substances are not involved in photosynthesis, examples of which are capsanthin, lycopene, and α -carotenoids. Furthermore, it is also classified as acyclic (e.g., lycopene) and bicyclic (e.g., β -carotenoids).

The carotenoid concentration in peppers depends on their maturity stages and colour. Researchers have reported that large amounts of carotenoids were found in red bell pepper (7237-8000 µg/g), follow-up orange (5293 µg/g), yellow (2336.3-2799 µg/g), and green (1220-1531.4 µg/g) peppers. During the mature stages, the chloroplast is converted into a chromoplast. Furthermore, the green pigment and chlorophyll content are reduced, and carotenoids are formed. The two metabolic processes of the carotenoid pigment profile are determined during the ripening stages: one is the transformation of green pigments, and the second is the biosynthesis of carotenoids. The variety of fruit colours depends on their maturity. In unripe conditions, fruits can be green and white, and in the case of ripening, it is turning to red, brown, and black. Fruit's various colours are mostly caused by the presence of carotenoids. Chlorophyll (151.1 µg/g), zeaxanthin (34.8 µg/g), capsanthin (17 µg/g), neoxanthin (192 µg/g), and lutein (77 µg/g) are the major carotenoid pigments which is found in the green pepper. While red peppers contain the richest pigments, such as zeaxanthin (70 µg/g), lycopene (322 µg/g) capsanthin (177 µg/g). Moreover, the orange peppers contain a high amount of lutein (46 µg/g), β -carotene (58.5 µg/g) and capsanthin (46.5 µg/g). Researchers have reported that the most common carotenoids, such as α -carotene (21 µg/g), lutein (121 µg/g), zeaxanthin (49 µg/g), and chlorophyll (61 µg/g) are found in yellow pepper [4].

Carotenoids serve an important function in our bodies, all of which are beneficial to our health. They have antioxidant properties, decrease oxidative stress, protect against CVD (cardiovascular diseases) and retinal degeneration, inhibit carcinogenic cells and cataracts, and have provitamin A activity. Multiple studies have demonstrated the advantages of carotenoid consumption against chronic diseases.

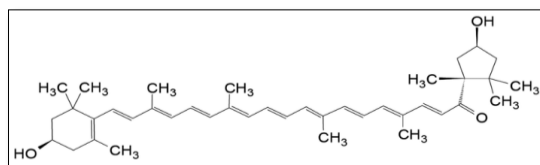


Fig.1. Capsanthin

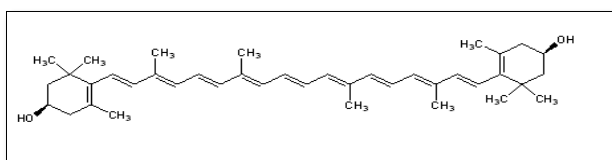


Fig. 2. Xeaxanthin

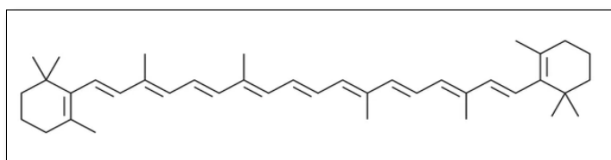


Fig. 3. β -carotene

3.3 Capsaicinoids

Capsaicinoids are secondary metabolites that give pepper fruits their pungency and give them a robust and fiery flavour. In the intercellular septum and placental tissue, a group of alkaloids is synthesised. In the fruit seed coat, seed tissues, and placenta of all peppers, dihydrocapsaicin and capsaicin are the major capsaicinoids that can reach levels of over 90%, while nordihydrocapsaicin, homocapsaicin, and homodihydrocapsaicin make up less than 10-15% of the total fruits. Biosynthesis of bell peppers is genetically determined characteristic, depending on the genome and also the environment. Researchers have reported that capsaicin provides a pungent oral feel; However, the leftover capsaicinoids could also have a moderately pungent flavour.

In 1876, capsaicin was first extracted from pepper, and in 1919, its structure was defined. Additionally, it can be made artificially by reacting vanillylamine with a chloride of 7-methyloct-5-ene-1-carboxylic acid. Capsaicin is constructed by a benzene ring with a long

hydrophobic carbon tail and a polar amide group. It's a white crystalline powder that's lipophilic, volatile, pungent, hydrophobic, colourless, and odourless.

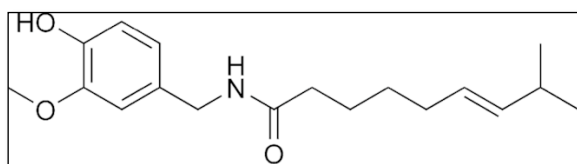


Fig. 4. Capsaicin

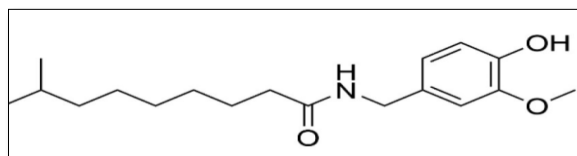


Fig. 5. Dihydrocapsaicin

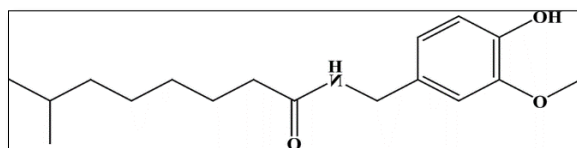


Fig. 6. Nordihydrocapsaicin

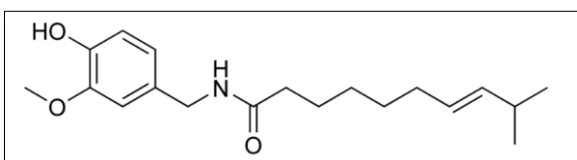


Fig. 7. Homocapsaicin

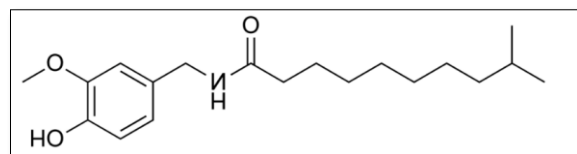


Fig. 8. Homodihydrocapsaicin

The pungency of capsicum spices is caused by capsaicinoids, which are non-volatile alkaloids, and C₉-C₁₁ branched-chain fatty acids. Capsaicinoid is a thermally stable compound that retains its stability after boiling; it is soluble in water, ethanol, and vegetable oils. The key variations between capsaicinoids and dihydrocapsaicin are the length of the hydrocarbon and the availability or lack of a covalent double bond. Historically, spectrophotometric approaches like ultraviolet and colorimetry have been used to examine capsaicinoids in meals. A pharmacist created the organoleptic method for determining the pungency of peppers. The Scoville test is now widely used around the world, although it is carried out using HPLC. Instead of the polyphenolic hydroxyl group of capsaicin, the C-7 benzyl carbon creates the scavenging site. 8-methyl-6-noneamide and vanillin (formation during oxidation) are the by-products of capsaicin. Capsaicin has applications in the food and biopharmaceutical industries.

Capsaicinoid content is a key indicator of pepper pungency, and Scoville Heat Units (SHU) is a pungency measurement devised by Scoville. Scoville established five different levels of pungency, such as extremely pungent, highly pungent, mildly pungent, moderately pungent, and Non-pungent. One person can consume in India 2.55 g/day, Mexico 20.0 g/day, Thailand 5.1 g/day, and Saudi Arabia 15.5 g/day. The total capsaicinoids in *C. annum*, *C. frutescens*, and *C. chinense* pepper cultivars range from 0.25 to 20.5 mg/g dw.

According to [6], disparity in the deposition of capsaicin can be related to inherent characteristics of each genotype and external conditions (environment). As previously established by researchers, levels of capsaicinoid molecules, notably capsaicin, may also vary based on the maturity or even with moisture stress during plant growth.

Another study has shown that fourteen pepper cultivars with varying genomes, pungency, and environmental factors found that genotypes contributed a crucial effect in capsaicinoid deposition. Researchers have shown that mature fruits and harvest conditions have an effect on the number of bioactive molecules, particularly capsaicin, by raising the quantities of pungent compounds. Researchers have investigated the three different pepper cultivars at two phases of maturation, and the quantity of these chemicals varied depending on the harvest period. In several pepper species, the maturation stages elevate the levels of both compounds.

3.4 Lipids and fatty acids

Small levels of lipid profile can be found in the edible section of the capsicum. The nutritional quality of lipids is dependent on their fatty acid composition. Essential fatty acids like Oleic, linoleic palmitic acids are mainly present in it. Linoleic acid is the most predominant in all pulp and seeds, a fatty acid that is present in seed and pulp, which are unsaturated fatty acids (apart from palmitic acid).

Linolenic acid (18:3n-3) is abundant in pulps but nearly non-existent in seeds. The ratio between PUFA (polyunsaturated fatty acids) and SFA (saturated fatty acids) for all capsicums is high due to the presence of linoleic acid. The higher polyunsaturated/saturated fatty acid ratio is beneficial to health by reducing total cholesterol. SFA and unsaturated fatty acids in pepper range from 14.52 to 16.73 % and 83.26 to 85.49% respectively. The incorporation of omega-3 fatty acids can modulate the metabolic pathways and has a positive effect on tumour cells. The predominant fatty acids in pepper are linoleic acid or omega-6, which maintain our normal blood cholesterol levels; hence, consumption of pepper seed is beneficial for human health.

4 Enzymes of Capsicum

Ascorbic acid is present in high amounts in capsicum. Ascorbate (AO) is the strongest antioxidant molecule and plays a vital role in cell division and expression by controlling processes of transport through the cell membrane during maturity, fruit ripening, and plant growth. The fast oxidative stress in plant cell walls undergoing a microbial attack is controlled by a superoxide oxidase enzyme. A crucial function of ascorbate peroxidase (APX) is to safeguard metabolic functions against H₂O₂ and other harmful oxygen derivatives. Peroxidase (POD) and Polyphenol oxidase (PPO) are both oxidative enzymes present in capsicum, which catalyse the oxidation of phenolic substrates due to enzymatic browning. The enzyme catalyses the phenolic compounds to o-Quinone, which produces undesirable pigments. Cellulose, arachidonic acid (AA), and methyl jasmonate (MeJA) are also present in capsicum, which reduces reactive oxygen species (ROS) of both plant and animal cells [7].

5 Therapeutic and Medical Properties of Bell Pepper

Food, as well as natural chemicals, has become a valuable source of components for the manufacture of medications and goods to treat a wide range of ailments and improve health and well-being. Peppers have shown potential as a blood glucose regulator, an anti-inflammatory, an antioxidant agent, and an analgesic, all of which contribute to a healthy lifestyle. Carotenoids, alkaloids, vitamins C and E, capsaicin, and flavonoids are all thought to have these functional qualities.

Capsaicin is becoming a popular element in pharmaceuticals due to significant reductions in total cholesterol, serum, myocardial, and neurological effects, aortic total cholesterol levels, and pain relief. As a result, it's advised for treating gastrointestinal issues, skin illnesses, and arthritis, as well as wound healing and blood purification. Capsaicinoids' ability to reduce inflammation, pain, oxidative stress, body weight, fat intake, and control dyspepsia is supported by experimental evidence; it is also known as an anti-atherosclerotic, anti-diabetic, anti-obesity, and anti-hypertensive substance.

Capsaicin's positive effects have been observed in a variety of pathological disorders. Postherpetic neuralgia, psoriasis, diabetic neuropathy, rheumatoid arthritis, vulvar vestibulitis, reflex sympathetic dystrophy syndrome, and post-mastectomy neuroma have all been studied in preclinical and clinical research with topical capsaicin. Obesity, cancer, cardiovascular disease, neurogenic bladder and gastrointestinal problems, and dermatologic conditions all benefit from it. Capsaicin has shown promise in preclinical tests for prostatic and lung cancer, as well as different forms of leukaemia. On the other hand, it has anti-tumorigenic potential as well as chemopreventive and chemotherapeutic capabilities.

5.1 The anti-obesity effect of pepper

Overweight and obesity have become a global epidemic in recent decades, and they are now considered a public health emergency. Capsaicin has anti-obesity characteristics through multiple pathways, including induction of body weight loss, satiety or fullness, lipolysis in adipocytes, and energy expenditure, as well as a reduction in calorie and fat consumption.

Capsaicinoids amplify the influence of daily calorific allowance on human body weight reduction. Capsaicin supplementation in the diet reduced appetite and increased fullness, fat oxidation, and energy expenditure.

The antioxidant properties of capsicum help you maintain a healthy weight after a low-calorie diet. Capsaicin ingestion one hour before low-intensity exercise enhances lipolysis, making it a useful supplement for those with hypercholesterolemia and/or obesity. Capsaicinoid consumption boosts an expenditure of energy by initiating adipose tissue in the human body. Furthermore, researchers observed that the flower extract of hot pepper (*C. annuum*) inhibited pancreatic lipase. As a response, lipase inhibition, which lowers triglyceride absorption, is a key strategy for controlling obesity.

By increasing the expression of adiponectin, dietary capsaicin decreased metabolic dysregulation in diabetic subjects. The hypometabolic response to food restriction is reduced when abdominal capsaicin-sensitive fibres are desensitised. Capsaicin therapy alters thermogenesis and the proteins related to lipid metabolism. In preadipocytes and adipocytes, capsaicin causes apoptosis and suppresses adipogenesis. Capsaicin's sensory and gastrointestinal satiety effects were discovered to improve fullness and reduce fat and, as a result, energy intake in both oral and gastrointestinal exposures; the larger elimination with oral exposure supports a sensory impact. Because its ability to reduce appetite also promotes fullness during energy balancing, while subjects were treated with capsaicin lowered their energy intake.

The hypoglycaemic characteristics of *C. annuum* were discovered by reducing the activity of α -amylase. The slower rate of glucose utilization and a reduced postprandial plasma glucose increase were produced by the slowing of carbohydrate digestion and the extension of total carbohydrate breakdown time caused by these enzyme inhibitors.

Capsaicin activates the sympathoadrenal system, which increases energy expenditure by regulating the thermogenic and anorexigenic actions of capsaicinoids. Its use minimizes the hunger and fullness that come with calorie restriction, and drop in fat oxidation and energy expenditure. These effects may help maintain body weight in a post-obese state by delaying fat loss resistance during a weight loss programme. Capsaicin has an indirect influence on calorie balance due to its analgesic properties, which promote sleep, hence aid energy balance management.

Human researches involving a broad variety of levels of pepper ingestion found that it helped people to reduce weight. Thermogenesis, energy expenditure, and fat metabolism are the major aims of peppers. Capsaicin triggers (Transient receptor potential cation channel subfamily V member 1) TRPV1, which raises subcellular minerals such as micronutrient levels (Ca) and activates the nervous system, inducing weight loss. The browning of adipose tissue has been recommended as an appropriate method to enhance metabolic health in the latest research investigations; browning reduces weight gain resulting from a fat-rich diet by activating thermogenesis. Obesity, on the other hand, is linked to a decrease in thermogenesis.

5.2 Bell pepper's antioxidant properties and cardiovascular protection

Antioxidant activity is an essential criterion for determining a food product's healthfulness. Antioxidants accumulate in capsicum during maturation due to the high levels of carotenoids,

phenolics, flavonoids, and vitamin A. The antioxidant effect of peppers is due to the presence of the *o*-methoxy group in addition to the OH group. Additionally, it effectively prohibits radiation-induced lipid peroxidation, enzyme activity, protein oxidation, and antioxidant activity loss. TRPV1 is distributed throughout the body and has a role in vascular autoregulation, vasoconstriction, and vasodilation. Capsaicin has been shown to have vasodilation property and anti-platelet effects in the rat mesenteric artery. Capsaicin also has a hypotensive effect, which is thought to be due to TRPV1 activation in the vascular endothelium. The prevention of myocardial infarction, coronary disease, and hypertension has a protective impact on the cardiovascular system, which is linked to its anti-oxidative potential [8].

Bell peppers have shown to have favourable impact on hyper-lipidemia and atherosclerosis in lab rats that were fed with an HFD (High Fat Diet obesity Rat model) by reducing endothelial dysfunction and oxidative stress, which might be a novel way to prevent coronary heart disease, according to, who also stated that peppers have high antioxidant potential and might be excellent natural bioactive compounds for use in functional components, dietary supplements, and additives.

5.3 Anticancer activity

The formation, development, and spread of cancer have all been linked to immunological response, inflammatory stress, and oxidative stress. Some plant and spice extracts have been demonstrated to cause G2/M arrest, reducing carcinogenesis, invasion, proliferation, metastasis, and migration by inducing apoptosis, DNA damage, and cell death.

New data have emerged in recent decades to support capsaicin's anticancer effects against certain carcinogenic compounds. Because of its synergistic impact with other organic substances, pure capsaicin has a weaker anticancer effect than pepper plant extracts. Capsaicin interacts with cancer-prevention drugs and enhances their potential utility in cancer treatment through interaction with other chemotherapeutic medications. The anticancer properties of capsaicin have targeted several transcription factors and cancer-related genes at various phases of tumor development. Researchers have discovered that capsaicin inhibits oncogenic signalling and tumour promoters while promoting the anti-tumorigenic biochemical pathway and related transcription factors.

Cell suicide, usually known as "apoptosis," occurs in complex organisms and serves to protect the organism as a whole. Capsaicin's function in this process is dependent on its ability to induce chromatin condensation and nuclear clumping, both of which are apoptosis signals. Researchers have demonstrated its effectiveness against some types of cancerous cells and recognition of malignant cells, including bladder, skin disorders, pancreatic, colon, breast, and prostate cancers. In recent decades, the anti-carcinogenic and potential of capsaicin have been the subject of a lot of investigation. Capsaicin promoted death in tumour islets due to its relationship with ROS formation and disruption of mitochondria; capsaicin hindered mitochondrial function, resulting in oxidative stress and eventually apoptosis.

According to several studies on various forms of skin malignancies, capsaicin may have a chemopreventive role. Some researchers have explored the chemoprotective benefits of capsaicin against cancer and mutagenesis caused by various agents in mice and humans. Based on favourable results from topical application, capsaicin is thought to inhibit the

cytochrome isoform. Researchers have studied that pungency-producing compound capsaicin has shown to have the ability to reduce the development of tumours.

5.4 Antimicrobial properties

Capsicum shows antimicrobial properties against Gram-positive and Gram-negative bacteria as well as fungi. Two pungent compounds (capsaicin and dihydrocapsaicin) found in capsicum have shown anti-microbial effects. The anti-helminthic activity was shown by capsicum, and the level of worms was reduced and controlled. Capsaicin acts as an inhibitor to reduce pathogens. Antibacterial activity of capsaicin and dihydrocapsaicin against gram-positive microorganisms (*E. faecalis*, *B. subtilis* & *S. Aureus*), gram-negative microorganisms (*E. coli*, *K. pneumonia*, and *P. aeruginosa*), and yeast (*C. albicans*) was observed. The concentration of dihydrocapsaicin is required to restrict the gram-negative microbes (0.6–5.2 µg/ ml) than the gram-positive microbes (2.6–8.1 µg/ml). Gram-positive bacteria are more resistant due to the outer peptidoglycan membrane. Capsaicin has antifungal properties, primarily against *Gloeophyllum trabeum*, *Trametes versicolor*, and *Penicillium expansum*. It can, however, be used for the treatment of herpes simplex virus (HSV) illnesses in pigs.

Similarly, many researchers have proposed that bell pepper products might be utilised for food borne disease management and they also produce novel antimicrobial agents for food preservation and/or product deterioration without the need for chemical preservatives.

6 Effect of Processing on Bell Pepper

The food industry has significant difficulty in preserving the reliability and shelf-life extension of perishable foods. Colour and pungency are the two most important aspects for the quality of capsicum. However, there are disparities in the quality of various processed goods based on the preparation techniques used to generate the products. Bioactive compounds, like ascorbic acid, β-carotenoids, and polyphenolic substances in bell pepper and antioxidant activity may be affected by temperature as given in Tables 2 and 3. Physical treatments such as smoke drying, solar drying, hot air drying, sun drying, and other thermal processes, unconventional treatments such as instant controlled pressure drop, extraction by solid-liquid and chemical treatments (calcium chloride, sucrose, sodium chloride, acidification) are all commonly used in pepper processing. The quality of pepper can be affected by several processing methods, such as physical, chemical, and non-conventional ways. There's also a potential that any structural changes made during the processing activities may have a detrimental impact on the nutritional value, such as causing toxicity or the production of anti-nutrients and allergic substances. Processed pepper products may be affected by these alterations in digestion, absorption, metabolism, and excretion [9].

6.1 Physical treatments have an impact on pepper quality

In the food processing industry, many physical techniques are used to process pepper. Drying or dewatering, steaming, canning, and freezing are the most common physical methods for preparing peppers. One of the most common ways of preserving peppers is dehydration. It entails removing water to the point where microbial spoilage and degradation responses are reduced to a minimum. Traditional sun drying, smoke drying, solar drying, and other high-temperature treatments are frequently used to dehydrate peppers (Table 2).

6.1.1. Hot air drying (HAD)

Pepper is usually dehydrated through hot air drying, which allows for quick and large-scale processing. Although it has been demonstrated that rising temperatures can prolong shelf life, preserving the pepper's commercial and biological quality has proven extremely challenging, such as significantly reduced product volume and deteriorating micronutrients, active flavonoid, and phenolic concentration, antioxidants, and spicy hotness. In addition, capsicum samples treated by moisture evaporation at low temperatures with pressures had considerably greater levels of tocopherol, ascorbic acid, carotene, antioxidant activity, and total phenolic compounds than those processed at higher temperatures and pressures (Table 3). Similarly, drying red peppers at 70°C for a shorter duration (5 h) was shown to be more successful in terms of retaining antioxidant activity, ascorbic acid, and colour than drying at a higher temperature (80°C for 5 h).

6.1.2. Sun Drying

Peppers are dried most regularly using either dryers or sunlight all around the world. Pepper goes through structural, nutritional, physical, and chemical changes as it dries in the sun, which can influence quality aspects including texture, colour, flavour, and nutritional content. Furthermore, reducing the moisture level to 9.90% on a wet basis is a complex procedure that might take up to 10 days. Traditional sun-drying processes have also been linked to microbial multiplication, insect and fungus infestations, mycotoxin contamination, and, hence, to a loss of pepper quality. Sun-dried peppers also had lower moisture content, crude protein, vitamin C, total soluble solids, and total phenolic composition, as well as lower capsaicin, homo-capsaicin, nor-dihydrocapsaicin, and dihydrocapsaicin concentrations. The samples that were dried in the shade were seen as typically related to toxin contamination by fungal activity, which is thought to be the primary cause of the degradation of final products.

6.1.3. Smoke dehydration

Smoke dehydration, which involves drying capsicum with smoke created by burning hardwood, is another prominent form of traditional dehydration processing. The Maillard reaction is responsible for the colour of smoke-dehydrated peppers. Even though smoke drying is a typical method for processing capsicums in third-world countries, there is little research on the bioactive contents of smoke-dried capsicums. Further study is needed to understand how smoke treatment impacts pepper nutrition.

6.1.4. Canning

It is a preservation technique for perishable and non-perishable food. Optimizing the process parameters is essential for preserving the physicochemical characteristics of canned foods because a variety of processing conditions, including blanching, preparation medium, stress, and the time-temperature combined effect used for processing, have an influence on the quality of packaged foods. Blanching for 2 minutes, processing for 10 minutes, and with 0.25-0.3% Na₂S₂O₅ treatment were shown to be effective in preserving the look and physicochemical qualities of canned capsicums.

6.1.5 Freeze drying

Lyophilisation or Freeze-drying is a cold drying technique used in the food industry that involves freezing the samples and then reducing the pressure and sublimating them to evaporate excess moisture from the food, which turns into ice crystals. It is a typical food preservation technique; there have been few investigations on the influence of lyophilisation on capsaicinoids and other nutrients.

The volatile element profile of peppers (*C. annuum*) did not significantly alter after freeze-drying when the impacts of freezing (freezing at -22°C) and lyophilisation were compared. Fresh peppers and lyophilised capsicum show a steady decline in vitamin C concentration.

6.2 Chemical treatments have an impact on pepper quality

The most frequent chemical processing for preserving raw, whole, or crushed capsicum is curing for prolonged periods in a high amount of vinegar or salt. However, excessive acidity was shown to have adverse effects on color retention and pungency, whereas high salt concentration promoted retention of color. Osmotic processing of capsicum with NaCl solution containing 17–26.5% w/w, temperatures (25°C to 45°C), and exposure periods (8 hours) had minimal influence on color change. Furthermore, it was shown that canned pepper with the treatment of 0.2 % sodium metabisulfite maintained its color and physicochemical qualities. However, 0.01 % potassium meta-bisulfite treatment reduced the vitamin C content of green capsicum and red capsicum powder while considerably increasing beta-carotene concentration. The dehydrated pepper samples enhanced texture characteristics and color retention after being dehydrated with sucrose ($\text{C}_6\text{H}_{12}\text{O}_{11}$) solutions or a mixture of sucrose with salt solutions. This type of osmotic dehydration may be able to eliminate the colour loss that often occurs when peppers are dried in the sun.

6.3 Impact of non-traditional treatments on pepper quality

To retain the nutritional content of peppers after processing, certain unconventional techniques have been used. *Capsicum annuum* was treated with an instant controlled pressure drop by first introducing the specimens to saturated steam at 0.10-0.60 MPa for 09–40 s, followed by an absolute pressure drop of roughly 5 kPa that approximates a vacuum, which caused an instantaneous vaporization of volatile substances in capsicums and cooling of the samples. The major bioactive compounds (phenolics and flavonoids, antioxidant activity) were successfully retained using instant controlled pressure drop assisted HAD and instant controlled pressure drop assisted freezing on green pepper.

7 Role of Bell pepper in Food Industries

7.1 Food additives/preservatives, colouring and flavouring agents

Capsicum is a crucial ingredient for the food industry due to colouring, preservative, and flavouring agents for making different foods like pizzas, sauces, pickles, and soups [10]. Different coloured bell pepper is the most extensively used seasoning ingredient on the earth, and due to their high pungency its ability to bring a unique flavour. It was once primarily used for seasoning/spices and high value medicinal plant. Pepper's applications have expanded to include processed and fresh vegetables, spices, food colour and extract manufacturing for the cosmetics industry.

Food manufacturers are looking for alternatives to complicated preservatives to escape the stigma of long chemical names. Consumers prefer items with "clean labelling" and no typical chemical preservatives. Capsaicin has antimicrobial action against gram-negative, gram-positive spoilage microbes and spoilage causing bacteria. Capsaicin adds to the spiciness/hotness of bell peppers, which can limit their use in some food systems.

Typhimurium was cultured into mueller-hinton broth and pepper sauce wells. *S. enterica* and *Y. enterocolitica* were fully suppressed at the maximum concentration (1:3 dilutions) of chilli sauce, but *E. coli* and *B. thuringiensis* grew unaffected. Chrysoeriol, dihydrocapsaicin, and capsaicin extracted by using a solvent like acetonitrile were investigated for antimicrobial efficacy against seven microorganisms: *Enterococcus faecalis*, *E. coli*, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Candida* Surprisingly, and *Staphylococcus aureus*, chrysoeriol had the highest activity against all bacteria tested with 1 g/ml under the circumstances studied.

To control infections, novel food processing technologies like UV-light, high pressure processing (HPP) and pulsed light, are becoming increasingly popular. It is necessary to evaluate the use of Capsicum-derived chemicals in conjunction with processing procedures that do not alter the food's organoleptic properties. Total spore inactivation was shown using 200-250 MPa pressure for 40-50 minutes and a bio preservative concentration (nisin) of 260 IU/mL. (Over 6 log) [11].

7.2 Antimicrobial activity on meat industry

Very limited attention has been given to the incorporation of capsicum in meat products given in Table 4. Capsicum in meat may assist to address the existing fibre deficiency among consumers, although the reducing the risk of colon cancer, obesity, and a variety of other ailments. The incorporation of raw carrot, raw radish and raw capsicum in mutton nuggets had potential to increase the dietary fibres and biochemically active compounds such as β -carotene and carotenoids. The vegetable incorporated communicated mutton products were also superior to control nuggets particularly because of capsicum.

Several types of research have demonstrated antimicrobial properties against gram-negative and gram-positive microorganism that cause foodborne illnesses. The phenolic acids, cinnamic and coumaric acids were found to be the major reason for the inhibitory effects of *C. annuum* pulp towards *Listeria monocytogenes*, *Bacillus cereus*, *Staphylococcus aureus* and *Salmonella enterica typhimurium*. The research found that a solvent extract of pepper was high in cinnamic acids, which had significant antibacterial activity, particularly against *L. monocytogenes*. These studies also found that capsinosides had antibacterial action against gram-positive micro-organisms, suggesting that prevention of biofilm development. Research have investigated that a minimal inhibitory dose of 1.5 mL 100 g/l of a pepper extract in red meat inhibited the development of *S. typhimurium*.

7.3 Edible coating preparation

Oleoresins are present in capsicum which mixed with chitosan made an edible coating which has antimicrobial activity against microflora and *Listeria monocytogenes* and significantly affected POD and PPO activity. Extract of capsicum was used in biofilm development of

pathogenic strains *Klebsiella pneumoniae*, *Pseudomonas aeruginosa* and *E coli* for antibacterial activity.

Three distinct polysaccharide/biopolymers (xanthan gums, arabic and pectin) were tested in combinations with candelilla wax as the lipophilic phase, jojoba oil as a plasticizer, and a crude polyphenol extract as a source of bioactive chemicals from the pepper. The fruits were submerged in water and then kept at ambient temperature. The following parameters were kinetically determined: weight reduction, total soluble solids (TSS), an appearance, colour, pH, and hardness variations. A lower level of degradation was seen in capsicum treated with edible coating developed with arabic gum compared to the control treatment (without edible coating), but appearance remained consistent among fruits treated with various edible coatings. Weight loss was seen in fruits treated with edible coating developed with arabic gum compared to the control treatment (without edible coating). The use of polysaccharide/biopolymers, jojoba oil, polyphenols and candelilla wax to create edible coating enhance the shelf life of fruits tremendously. Six distinct characteristics were monitored during the storage time to analysis the shelf life of the peppers, with sampling every 48 hours. An analytical balance was used to determine how much weight had been lost. A photographic camera was used to assess the changes in appearance. TSS content was measured using a hand refractometer with a capacity range of up to 45° Brix, according to the A.O.A.C. technique. A portable colorimeter was used to record the colour of green bell peppers using the L* a* b* technique. Furthermore pH was tested by using pH meter.

Capsaicin having antioxidative, anti-obesity, anti-inflammatory, analgesic and anti-cancer effects were employed. Food-packaging materials made of chitosan-capsaicin mix films are available. To make edible films, chitosan (a flexible polymer) were mixed with three distinct doses of capsaicin. FT-IR, SEM, and DSC were used to characterise the generated films. It was also tested for mechanical, antioxidant, hydrophobicity and antibacterial characteristics. The addition of 0.5-0.7 mg of capsaicin/dehydrocapsaicin to the fish by product like chitosan matrix was shown to be the best concentration for improving up to three film characteristics that isoptical, surface morphology and mechanical. With raising concentrations of capsaicin/dehydrocapsaicin in the bio-film improved the characteristics such as antibacterial properties, anti-oxidative and hydrophobicity. Food-packaging materials made of chitosan-capsaicin mix films are available.

The mechanical characteristics of chitosan sheets containing capsaicin were investigated. The mechanical qualities of any biodegradable film are typically determined by the application. However, in general, a biodegradable film should be able to withstand typical stress and preserve its integrity during application. Tensile strength (TS) values for chitosan film (the control) were measured as 27.23 2.59 MPa in a recent study. The TS content of capsaicin included chitosan bio-films, which were 20.31 1.45 MPa, which were significantly lower than the control film. The modifications in the film structural organisation generated by the developed of capsaicin can be linked to the drop-in TS of capsaicin-developed bio-films.

Elongation at break (EB) was significantly increased in capsaicin-infused chitosan films; the control was 3.73±0.52, and the sample was 4.4±0.12 %. This enhancement is carried on by the development of two intra- and inter-molecular hydrogen bonds between both the hydroxyl or amine groups of chitosan and the polyphenol hydroxyl or carbonyl groups of capsaicin.

Film rigidity is measure by Young's modulus (YM). The greater the YM, the more stiff the film. Capsaicin was used to lower the YM of chitosan bio-films. YM was re-wired as

1346.82±15.48 MPa for the control. The capsicum chitosan film, on the other hand, had YM of 867.05±28.59 MPa. This might be owing to rich amount of capsaicin being deposited on the bio-film surface, causing it to distort.

The micro structural modifications after incorporating capsaicin into chitosan-based films were studied using scanning electron microscopy (SEM). The chitosan control film's surface shape was described as planar, even, and homogenous. The addition of 0.35 mg capsaicin did not effect on the film's surface texture since it was evenly distributed throughout the film. When the capsaicin level was raised to 0.6 mg, the film became smoother, cleaner, and more uniform than the chitosan control film. The thorough and uniform distribution of capsaicin in the picture is responsible for this phenomenon.

7.4 Applications in Dairy products

The addition of extracted Oleoresin from capsicum to yogurt will result in a new composition with improved functional qualities of food (Table 4).

The water contain of all yogurt sample supplemented with oleoresin extracts was found to be lower. The water content of yogurt decreased as the number of extracts increased. This might be due to the addition of oil that is devoid of moisture. Apart from carotenoid pigments, neutral lipid (tocopherols), capsaicinoids and essential oil were also observed in the extract, which was recovered from the capsicum tissues and seed. The amount of ash was significantly reduced with extract added sample. It was previously recognized that the quantity of organic chemicals and salt entering the raw material affects the quantity of ash value. It's possible that the minor reduction in ash content is due to by lowering the salt ratio and the number of organic molecules with the addition of extracted oleoresin to yogurt samples.

The spicy flavour found in Capsicum fruit is known as capsaicinoids. Capsaicinoids and capsaicinoid-like compounds found in red bell pepper extracts are used in modest amounts for food colouring. The addition of bell pepper extract at various level enhanced the value of a^* and b^* were differentiate to the control group, whereas the L^* (lightness) value decreased dramatically. The colour attributes of peel extract (PE) and peel and seed extract (PSE) samples were more affected than those of seed extract (SE) samples. In general, all extracts generated red condensed products, while PE had a more vivid hue. As a result, there was a bigger decline in L^* (lightness) values in these samples, but there was a hugeraised in a^* and b^* values.

Carotenoids, flavonoids, capsaicinoids, phenols and vitamins are among the physiologically active components found in red hot pepper. Colour pigments, cellulose, pungent chemicals, resins, mineral, and protein components are all found in them. Even it contains minimal volatile oil, whereas seeds have fixed (non-volatile) oil. The sensory characteristics of fortified yogurt samples are influenced by these factors. The yoghurt sample added with peel and seed extract received the best score for colour and appearance.

7.5 Antimicrobial activity on cheese industry

Debaryomyces hansenii and *Penicillium expansum* (mycotoxin producer) were among the fungi to which *C. annuum* extracts showed inhibitory efficacy (opportunistic pathogen).

Ethanol extracts of green bell peppers were also used in the production of kareish cheese and showed antibacterial efficacy against moulds, coliforms, microflora and *Staphylococcus aureus*, as well as being very acceptable to customers at concentrations of 4–8% (w/v) for green pepper.

In order to avoid using other artificial preservatives that have been associated with allergic reactions and the production of nitrosamine, capsicum derivative products may help to develop modified and healthy components that might be used as anti-bacterial compounds for preservation of foods, to restrict microbial contamination in foods, and/or to prevent quality deterioration.

8 Role of Bell Pepper in Nano-particle Synthesis

Nanotechnologies with their unique characteristics play vital role in a broad spectrum of scientific domains. With specialized biological, chemical and physical features like durability, maximum permeability, resilience, chemical stability, antimicrobial, electrical conductivity, catalytic, and antioxidant capabilities, nano material research has flourished. Antibacterial nanoparticles have been extensively employed in medicinal applications. However, the primary aim of green synthesis is to use natural resources to tackle sustainability issues. It creates nanoparticles using the minimum amount of resources even while ensuring that they do not affect the environment or human health. A green nanoparticle synthesis is a simple approach that produces no toxic by-products as compared to traditional methods. Cleaning toxic waste, removing environmental contaminants, desalinating water, medicinal medications, leathers, and sunscreen goods all use green nanoparticles. Green nanoparticles are also used in various sectors for their high efficiency and abundance (Table 5). As a result of human activity, the world's environmental degradation crisis is worsening on a regularly. Healthy lifestyles, it must be minimized by adopting green technology in all industries. The major advantages of green NPs are cost-effectiveness, high efficiency, greater production, eco-friendly and low energy usage.

Many plant components, including seeds, fruits, bark, stems, gums, leaves, and flowers, can cap and stabilise nanoparticles. As a result, they are employed in the safe, environmentally friendly production of NPs with biological applications. Phenols, tannins, alkaloids, flavonoids, proteins and polysaccharides, among other phytochemicals used in green nanoparticle synthesis, are an excellent natural source which are safe in producing NPs with maximum stability and desired form and shape for better potential uses. Green NPs are extensively accepted and employed in the cosmetics, textiles, and plastics sectors, as well as medicinal, pharmacological, and agricultural domains.

At standard temperature, solutions of red pepper (*Capsicum annum var. aviculare*) catalysed oxidation/reduction reactions of dilute AgNO₃ solutions, leading in silver-based nanostructures[12]. The product was found to be made up of silver nanoparticles after detailed micro structural and morphological examinations utilising x-ray diffraction, high-resolution transmission electron microscopy and electron diffraction and.

The use of red pepper extract to induce the cost-effective and long-term synthesis of silver nano crystal has been demonstrated. Because of the range of bio active molecules present in the reaction media, many reactions take place simultaneously, creating metallic silver nanoparticles. The formation of these nanostructures is mostly caused by the interaction of

silver ions with the amino nitrogen atom of peptides, capsaicin, along with the oxygen molecule of the -OH of polyphenolic substance.

Due to their high surface-to-volume proportion, nanoparticles frequently self-assemble and consolidate to form single-crystalline and attend Ag NPs with diameters between 10 and 100 nanometres that are coated with an organometallic upper layers and biomolecule fragments.

As a result, it has been shown that using pepper fruit extracts as a reaction mixture in the formation of NPs, which are sustainable and cost-effective ways to create functional nanomaterials, also introduces creative experimental methods for the investigation of innovative crystallisation concepts, such as complex crystal production phenomena and the emergence of new organometallic crystalline phases.

The anti-bacterial effect of the synthesized Ag NPs is strong against gram-negative and mild against gram-positive bacteria. Ag nanoparticles have an antibacterial effect by binding to microbe membranes via electrostatic interactions, disrupting cell walls, and altering intracellular processes such as DNA, RNA, and protein production. It demonstrates the tremendous potential of biological applications [13].

9 Other Beneficial Effects of Bell Pepper

9.1. Insecticidal activity

Capsicum has insecticidal activity against *Rhyzopertha dominica* and *Sitophilus granaries*. Wheat grain was mixed with capsicum powder in different concentrations 0, 0.5, 0.85, 1.5, 3 and 5% (w/w) after that it did not complete mortality on 2 pest after 14±1 days but cause a complete depletion of *R. dominica* and *S. granarius* at highest tested dosages.

9.2. Antibiofilm activity

According to research, the differential between the intensity at 600 nm was obtained at the start (t = 0) and end (t = 24 h) of the experimental period in polystyrene dishes was used to assess nosocomial bacterial growth. Instead of extract, the specimens (untreated, regarded 100 % growth of bacteria) received Milli-Q water or 1% DMSO. For growth defeat against *P. aeruginosa*, gentamicin sulphate (7.5 g/ml) was used as a control sample, whereas rifampicin (6.5 g/mL) was utilised as supervision over *S. epidermidis*.

Extracts from the seeds and fruits of the red bell peppers were tested for anti-biofilm activity against *P. aeruginosa* PA14 and *S. epidermidis* ATCC 35984 after preparation. Surprisingly, 3.2 % seed extract by water was substantially reduced *S. Epidermidis* and *P. Aeruginosa* bio-film development. Accordingly, the concentrations level of around 2.1 mg/ml and 4.2 mg/ml suppressed *S. Epidermidis* biofilm by around 33% and 80%. At a dosage of 4.0 mg/ml, seed extract was able to suppress % *P. aeruginosa* biofilm, 50 % at 2.0 mg/ml, and 40 % at 1.0 mg/ml. The bio-film of *P. aeruginosa* was reduced by around 20-25% at doses of 0.5 and 0.25 mg/ml [14].

Because an essential virulence component is blocked, the promotion of microorganism growth might be attributed to stress generated by the seed extract treatment. Biofilms are

frequently the source of difficulty in removing germs, posing a problem in a variety of settings, including the food, medical, and ontological industries.

9.3. Application on cosmetic and pharma industry

At present eco-conscious behavior of customers and production unit, it is noticed that tremendous attraction in finding phytochemicals, raw plant sources, or extract of plants as organic materials for cosmetic and medicinal purposes. In this regard, various features that might affect the final goods quality (texture, colour, permeation or flavour) and biotechnological applications, should be investigated and approved by the appropriate proficient authority. Natural compounds, rather than synthetic preservatives, might improve the health characteristics of cosmetic and medicinal items while avoiding the adverse effects of contact allergies.

Carotenoids and capsaicinoids are abundant in capsicum powder and oleoresins, making them a great source of colour in the nutraceutical, pharmaceutical and food sectors. These natural components do not require particular clearance from these organisations, according to the FDA. It must be safe for customers and producers to have legal documentation for the protection of their goods and components. So that, peppers are frequently used as a seasoning and its usage as a cosmetic colour has no known negative side effects because it is approved as a food additive. The bioactive chemicals of capsicum can also be employed as flavouring or aroma compounds in cosmetic goods.

Capsicum product is used to product stability and preservation, to prevent the oxidation of active compounds and inert ingredients in drugs due to their antioxidant qualities. The antioxidant potential of these bioactive is regulated by their nature, the pharmaceutical product's production processes, the container's type, and the formulation. Antioxidants can also act in three ways, first by interacting with free radicals to retard the reactions, second, by act as reductants, such as vitamin c which has a less reduction potential than the excipients and thus protects them, and third, by boost the effects of other components already present in the product. This scavenging of free radicals effect improves the long-term firmness of the finished goods and contributes to its advantageous properties, such as the treatment of skin problems. In the cosmetic sector, dried green pepper with high vitamin C content (1.4–2.5 mg/ g DW) might be utilised as preservation antioxidant[15]. Capsicum extracts holding carotenoids like lutein, capsanthin and zeaxanthin that have been extracted by lipophilic solvents might also be employed as active ingredients in skincare products. Indeed, incorporating them into lipoproteins or membranes might improve their bioactivity and stability.

Antimicrobial inhibitors have been used to reduce the bacterial, moulds, and fungal growth, that might lead to infection or breakdown of medical or personal care goods, which often have a shelf life of more than three years. P-coumaric acid cinnamic acid and other bioactive molecules found in solvent extracts, showed strong antimicrobial activity against *Salmonella typhimurium*, *Staphylococcus aureus*, *Bacillus cereus* and *Listeria monocytogenes* inactivating or inhibiting the growth of microorganisms in industrial products.

However, as customer demand grows for products produced with natural substance, the use of natural preservatives in the cosmetics industry will expand in the coming years.

10 Conclusion

Capsicum is popular, valuable and commonly used vegetable in our daily life. This review article discusses the bioactive component of capsicum as well as its potential application in Nanotechnology, development of functional food etc. The main bioactive component capsaicin is very beneficial as an antioxidant and responsible for pungency. The phenolic and flavonoid compound in capsicum has promised health promotion according to this review. Peppers have various functions and appear to be promising in the prevention of metabolic syndrome. It is an affordable source of vitamin C, phenolic and flavonoid components, carotenoids, lipids and fatty acids. Due to its perishable characteristics, different types of drying methods (microwave drying, hot air drying and fluidized bed dryingetc.) are used to preserve capsicum to an increase shelf life. Phytochemicals obtained from Capsicum plants are also promising for food preservation and safety. Combining capsaicin and dihydrocapsaicin with non-thermal processes, other natural antimicrobials for example, may result in safer goods without chemical preservatives for customers. However, the needed dosages, the processing duration of the non-thermal technology used, and the sensory qualities of each item should be assessed. This opens up the possibility of future study into other enzymes from Capsicum components that need further investigation.

Acknowledgment

I sincerely appreciate Dr. Runu Chakraborty for her scientific advice for this review.

Conflict of interest

All authors have no conflict of interest.

Table 1. Carotenoids, phenolic acids and flavonoids present in different types of green pepper

Sl No	Group	Bio active compounds	Green bell pepper($\mu\text{g/g}$)	Orange bell pepper ($\mu\text{g/g}$)	Red bell pepper ($\mu\text{g/g}$)	Yellow bell pepper ($\mu\text{g/g}$)
1	Phenolic acids	Galic acid	89.98	900	115.74	119.48
		Caffeic acid	108.82	38.03	67.78	52.42
		Benzoic acid	66.55	-	23.17-111.81	173.04
		Myricetin	658.19	100.62	244.33	151.35
		Resveratrol	174.34	89.72-101.2	111.57	90.78
		Ellagic acid	99.10-106.67		172.18	144.52

		Sinapic acid			117	-
		Vanillic acid	43.85-67.19		11.17-11.70	31.62
2	Flavonoids	Quercetin	-		34	
		Kampferol	22.48		31.15	9.53
		Epicatechin	-		505	-
		Rutin	81.77-93.45		290.39	49.51
		Naringin	13.64		50.13	190.19
		Luteonin	62.31	154.03	11.0	2.0
3	Carotenoids	α - carotene	3.56	9.02		4.22-21.27
		β -carotene	1.86-12.2	56.6	5.4	0.2
		Retinol	0.313-1.09			1.57
		Zeaxanthin	35-41.26	191.76	8.8-70.71	48.3
		Lycopin			4.8-322	2.5
		Capsanthin	16.15	45.48	8-14.19	45.48

Table 2. Effect of drying on antioxidant activity of peppers

Sample	Antioxidant activity (μmol Trolox equivalent antioxidant activity (TEAC)/100g DM)	DPPH free radical scavenging activity (%)	FRAP ($\mu\text{mol TE/g}$)	Measurement of superoxide dismutase (SOD)	Copperreducing antioxidant capacity (CUPRAC) ($\mu\text{mol TE}/100\text{g}$)
Sun-dried sample	5564.60	25-76.14	6.22-31.9		

Oven-dried sample at 50°C	4431.14	67.02	321.56	44%	
Oven-dried sample at 70°C	5000.53	73.25	351.57		
Micro wave dried sample at 700W	5271.92	74.03	49.7 mg/100g		
Micro wave dried sample at 210W	4840.89	68.97	10.4 mg/100 g		
Freeze dried sample at -40°C	2730	15.35(µmo ITE/100g)	31.08		65.2
Drying at room temperature (25 °C)			1.175mg/ml	22%	

Table 3 Effect of drying on bioactive compound of bell pepper

No	Drying techniques	Parameters	Effects on chemical properties
1	Comparisons between pulsed vacuum drying and hot air drying	Temperature -60, 70, 80°C. Time-20 min Velocity of air was maintained at 1.5 m/s Heating system using 250W infrared radiation thermal plates.	1. In PVD provided superior phytochemical properties such as brighter colour, lower browning index and higher ascorbic acid content. 2 Furthermore, PVD resulted in a more porous structure, whereas HAD resulted in a less porous one.

2	Pulsed vacuum drying pepper (PVD) treated with high humidity hot air impingement blanching (HHAIB).	Thickness of pepper -9 cm, wind speed -14 m/s, humidity 35-40 %,drying Temperature - 70°C, pressure time -3 min and vacuum time -12 min.	<p>1. PPO activity was reduced 20 % after treated with high humidity hot air impingement blanching.</p> <p>2. Dehydration time was reduce after blanching</p> <p>3. Due to blanching treatment bound phytochemical substances were relished.</p> <p>4. Due to High-Humidity Hot Air Impingement Blanching (HHAIB) treatment drying rate and colour properties was enhanced.</p>
3	HAD(40,50,60° C) pepper with pre-treatment by blanching, blanching with ascorbic acid and blanching with citric acid.	<p>a. Blanching with water at 98° C for 240 s (treated as control)</p> <p>b. Blanching with ascorbic acid (BAA) for 83° C for 120 s +sample was dipped in ascorbic acid solution for 10 min.</p> <p>c. Blanching with citric acid (BCA) for 83° C for 120 s +sample was dipped in citric acid solution for 11-12 min.</p> <p>d. Combined blanching for 84°C for 110 s +sample was dipped in 5% mixture of both organic acid at 1:1</p>	<p>1. In combined blanching with 60° c temperature in HAD was found best phytochemical properties such as Polyphenols (709.50 mg/100g), flavonoid 363.41 mg /100 g ,ascorbic acid 178.13 nmol/lit.</p> <p>2. In combined blanching colour was preserved also reduce drying time.</p>

		ratio for 11-15 min	
4	Analysis of physico chemical properties by freeze and hot air drying	1.HAD temperature -40,50 and 60°C 2.FD temperature - 50°C and pressure is 0.06 m bar	1. Higher rehydration ration was observed in freeze dried pepper sample. 2. Highest drying temperature (60°C) increase the phenolic and flavonoid content. 3. Free radical scavenging activity was reduce in freeze dried bell pepper.
5	Microwave assisted fluidized bed dryer at different drying condition	Microwave power -180-540 W Air temperature 40-70°C Velocity of air is maintained around 10-25 m/s	1. Best result was found in 568 W, temp - 60.14°C, air velocity 16.82 m/s. In this condition the best bioactive components are found such as ascorbic acid content (178 mg/100 g), TPC (102 mg GAE/100g dw), TFC (33 mg QE/100g dw),carotenoid content (7.5 mg /100 g),DPPH radical scavenging activity 83 % and rehydration ratio 4.4. Total colour changes was reported 20.87.
6	Freeze drying by different pre-treatment process.	1.Blanching with water (BL) 98°C, 3 min 2. Ultra sound treated sample – sound intensity 3 W/cm ² frequency - 21 kHz, time-30 min. 3.Pulse electric field treated sample –electric	1. FD time and energy consumption is reduce while treated with BL, PEF, US, and PEF-US. 2. BL sample showed highest porosity value. 3. Colour changes were found for US pre-treated bell pepper ΔE 9.4, where other ΔE 15.2-28.5.

		field intensity-1.07 KV/cm Specific energy intake (Ws)-1 KJ/kg 4.Sample treated by both PEF-US Pulse no - 12,Electric field was maintained at- 1.1 KV/cm, time- 30 min Energy intake (Ws)-1.05 KJ/kg, FD done at - 40°C,63 K Pa.	4.Improve sustainability of FD process and quality of pre-treated FD pepper.
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Table 4 Role of bell pepper in functional food development

Food system	Food product	Aim	Distinct feature
Dairy product	Yogurt	Enhance the functional properties of yogurt by enriching different parts of capsicum (seed extract, peel extract, peel and seed extract).	1. Moisture content is less in oleoresin enrich yogurt than peel extract enrich yogurt sample. 2. Ash content is significantly low in oleoresin enrich yogurt. 3. a* and b* value is increase by the addition peel extract.
	Yogurt	Enhance the nutritional characteristic of yogurt by enriching bell pepper waste.	FD with pepper waste were significant for nutraceutical food development, with enhance nutritional quality, colour and phytochemical properties.
	Cheese	The effect of addition different colour of pepper juice (BPJ) as a functional ingredient in the fortification of processed cheese.	1. Enrich of different BPJ in process cheese can be improving its antioxidant activity, vitamin content and polyphenol activity. 2. Enrich of different BPJ in process cheese can be improve organoleptic, physical and functional properties.
Bio-film development	Formation of bio film	Aim of this study is to reduce the fungal growth (Anthracnose) of	1. The mixture of chitosan and essential oil demonstrated that improvement of overall food quality such as colour, titratable

		bell pepper by incorporation of chitosan and lemongrass oil.	acidity, soluble solid concentration and firmness. 2. When used in an actual food system, the addition of chitosan improved the quality of essential oil. 3. Overall, combination of chitosan and essential oil can acts as an antibacterial agents by replacing of synthetic fungicides.
Meet product	Edible coated meet	The effect of capsicum-starch bio-composite on meet.	1. Antimicrobial activity against gram negative bacteria. 2. It has significant effect on polyphenol oxidase.
Bakery product	Flat bread	The effect of fortification on different type of pepper in flat bread.	1. Flat bread fortified with 1.5% bell pepper powder having high phenolic content and antioxidant activity. 2. Product when incorporated with bell pepper paste showed brightness of colour and also good appearance.
	Alginate bread	Development of alginate bread by incorporating fresh cheese labneh with phytochemical compounds from bell pepper.	1. The addition of various pepper extracts in encapsulated in alginate breads to labneh cheese did not influence the chemical and microbial properties of the new product. 2. Highest content of phytochemical components and free radicals scavenging activity found in final product.
	Muffin	Fortification of red capsicum pomace powder in muffins	1. Fortified product shows that improvement of antioxidant activity (DPPH 13.04 μ mol TE/g) and total carotenoid content (3.46 mg/100 g). 2. Fortified muffin was improved that the quality of colour, flavour and texture. 3.6 % of powder incorporated muffin shows best results for porosity, crust uniformity and better softness of final product.
	Function al bread	Red bell pepper fortified bread.	1. In 6% red bell pepper enrich bread observed a substantial rise in bio active compound.

			2. Fortified bread had a highest sensory scores (8.5) and index of acceptability 87.9%.
Extruded product	Pasta	Capsicum juice incorporated pasta.	1. Protein (17.81%), antioxidant content (18.12%), and phenolic content (342.27 mg/100 g) will increase after addition of capsicum juice in to pasta. 2. The pasta samples with more pepper extracted juice shows greater rehydration ratio (2.57) and less solid loss (2.42%).

Table 5. Bell-pepper/ extract as an agent for nanoparticle synthesis

Extract used	Nanoparticle synthesized	Characterisation	Application studied
Extract of <i>Capsicum annum var aviculare</i> .	Silver NP	FTIR, UV-Vis, X-ray diffraction, TEM,EDS.	Capsaicin and protein as well as phenolic substances are the main active chemicals responsible for Ag ion reduction.
Leaf extract of <i>Capsicum frutescens</i>	CuO NP	UV-Vis, X-ray diffraction, FTIR, Dynamic light scattering, SEM.	1. The biofilm activities and anti-microbial against gram positive (<i>Listeria monocytogenes</i> and <i>Basillus anthracis</i>) and gram negative (<i>Klebsiella pneumoniae</i>). 2. Anti-diabetic and anti-inflammatory activity. 3. Application in the bio-medical and biotechnological field.
Pulp extract of <i>Capsicum annum var gossum</i> .	Gold nano particle (GNP)	TEM, XRD, ESD, FTIR.	It was showed good catalytic activity also well dispersed capacity.
Fruits extracts of <i>Capsicum frutescence</i> .	Silver NP	SEM, XED, UV-Vis, FTIR, X-Ray spectroscopy .	1. Anti-bacterial activity against gram positive and negative (<i>E.coli</i> & <i>B. subtilis</i>) was evaluated by measuring the diameter of the zone of inhibition .

Fresh cut bell pepper(<i>Capsicum annuum</i>)	Silver nano partical – polyvinylpyrrolidone(PVP)	XRD, PSA, FTIR, FE-TEM, EDS.	1. This nano partical shows antibacterial activity. 2. Increase the self-life of products. 3. It acts as a preservative agents. 4. It can't shows any toxicity to against round worm.
Fresh cut bell pepper(<i>Capsicum annuum</i>)	Chitosan – Sodium tripolyphosphate pentabasic (STPP)	UHR-SEM,FE-TEM,XRD,FTIR,DPPH,ABTS,MIC(Minimul inhibitory concentration),MBC(Minimul bactericidal concentration)	1. The antibioflim activity of MBC of chitosan nanopartical (CSNP) was shown to be promising .As a result the chitosan nanocoating was prepared with 3% CSNP and coated to the surface of the fresh cut pepper (FCP) to prevent microbiological contamination such as fungi, bacteria including <i>listeria monocytogenes</i> , <i>salmonella enterica</i> . The application of CSNC maintain the FCP for 12 days at 5°C without loss of weight.

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