INVESTIGATING THE PHARMACOLOGICAL ACTIVITIES OF DISTINCT CITRUS PLANT VARIETIES I, E. KARNA RAFF. (KHARNA KHATTA), C. PSEUDOLIMON TANAKA (GAL GAL), AND C. PARADISI VAR. FOSTER" FOR MANAGING OBESITY AND DIABETES

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Abstract: The process of removing bioactive flavonoids from citrus peels has the potential to help fight diabetes and obesity. It is now feasible to extract these molecules with great efficiency and purity because to developments in extraction methods and computer-aided drug discovery. This approach aligns with the economic cycle's principles, promoting health and environmental sustainability in the pharmaceutical and nutraceutical industries. According to the study, these flavonoids may work in concert to lower morbidity and death.

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Citrus fruits contain bioactive chemicals that exert diverse modes of action, such as direct impacts on glucose metabolism and adipogenesis, as well as indirect regulation of oxidative stress and inflammatory pathways. Citrus peel extraction of these chemicals is being refined for maximum purity and efficiency. The goal of this project is to create focused therapeutic activities with citrus different varieties, which might lead to the advancement of novel treatments for obesity and obesity-related metabolic diseases.

Introduction

Citrus is the single of the top most widely grown yield worldwide, and it demand and availability have influenced human foodstuffs. It is also referred by the Romance loanword "Agrumes," which means "sour fruits." Due to their broad cultivation areas and unclear genuine population sizes, citron fruits of productive significance primarily comprise of oranges, lemons, limes, grapefruits, and mandarin orange. Citrus fruits are grown in more than 140 countries widespread, but the numerous of the crop is produced in major Northern Hemisphere regions. This belt near the equator covers tropical and subtropical regions of the world at latitudes of 35°N and 35°S. (Liu et al., 2012).

Morphological and Photochemical Features of the Rutaceae family

The Citrus species, belonging to the Rutaceae family, is renowned for its diverse range of fruit-bearing plants that have been cultivated for long period of time. The majority of Rutaceae species are woody, however some genera have low growing woody shrub and herbs. All through nature, the utmost noticeable morphological features of the family is the existence of schizogenous secretory compartments that hold essential oils. The cavities may be seen as pellucid spots on the leaves as well as in the outer surface, flowers, and not ripe sections of the plants. This feature is seen in almost all Rutaceae, otherthan a few species in the prior branching Cneoroideae tissues. In certain subdivision, such as Phellodendron Rupr, the campartments may be inconspicuous and less common. (Appelhans et al., 2021).

Morphological Characteristics and Phytochemical Diversity in Rutaceae

Most morphological characteristics of Rutaceae are highly varied. Commonly, fruits are either dehiscent, with the seeds either malleable ejecting from the fruit or continue connected to the unwrapped via the funicle. Despite the reality that Engler (1896) catergorized Rutaceae into six or seven subdivisions mostly based on fruit traits, more novel morphological research and phylogenetic analyses have demonstrated that fruit essential quality are ineffective for identifying the substantial Rutaceae groups. Many other physical characteristics also seem to be homogeneously inappropriate since they are variable. A wide diversity of secondary metabolites are known to be produce by the Rutaceae family, many of which are unique or very detectable. Quinolones and acridones produces from anthranilic acid, limonoids, coumarins, and acetophenones are in the middle of the characteristic metabolites of the Rutaceae family. Before molecular research synthesis, phytochemistry provided helpful insights into the developmental relationship within the Rutaceae family. The identical chemical composition and phytochemical similarities of genera that were earlier assigned to definite subfamilies, indicating that these subfamilies are unnatural, are two considerable phytochemical results. (Karp et al., 2023).

Nutritional and Pharmacological Qualities of Citrus Species

These citrus plant varities deliver natural products that are tall in supplements as well as a assortment of pharmacological qualities. For the most part include of species that are individuals of the "Citrus" class, as lemon (Citrus limon (L.) Burm. F), orange (Citrus sinensis (L.) Osbeck), mandarin (Citrus reticulata Blanco) and grapefruit (Citrus paradisi Macfie) . (Bozkurt et al., 2017).

Complex Pharmacognosy and Unique Morphological Traits Of distinct Citrus Plant Varieties i.e., Karna khatta, Gal gal and Grapefruits:

These have long been of interest because of their rich cultural usage, complex pharmacognosy, and unique morphological traits. Investigating the pharmacological activities of citrus plant varieties, specifically concentrating on Karna Raf. (Kharna khatta), C. pseudolimon Tanaka (Galgal), and C. paradisi var. Foster, provide a fascinating observation into the quiescent health benefits and medicinal properties of these citrus fruits. Citrus plants have been revered for centuries for their revitalizing taste and aroma, but emergent research suggests they may also protect a wealth of pharmacologically active compounds that could have significant indications for human health.

Chemical Composition and bioactive Components

This comprehensive exploration seeks to separate out the multifaceted pharmacological activities exhibit by these sour fruit varieties, reveal their potential health giving uses. Through an comprehensive examination of the chemical make up of these fruits, extensive their essential oils, flavonoids, phenolic compounds, and other bioactivecomponents, we aim to illuminate the underlying process driving their remedial or pharmacological effects.

Health Benefits and Therapeutic Applications

This consideration will give beneficial insights into the complicate interplay between the constituents of Karna Raf., Galgal, and C. paradisi var. Foster, shedding light on their potential health benefits and therapeutic applications. (Pimenta et al., 2017).

a. Karna Khatta

Marphological Characteristics

Citrus karna Raf. (Kharna khatta) is characterized by evergreen in nature, typically growing to a medium height of 10 to 20 feet upon maturity. The fruits of this citrus variety are normally ellipsoidal or slightly oval in shape, with a show off thick peel full of essential oils that ripens to a bright yellow or orange color. The branches of citrus karna Raf. may or may not have thorns and tend to grow in a spreading, bushy manner with prominence smooth bark. The unique shiny, alternating, ovate or elliptical leaves adore the braches of citrus karma Raf., release a unique aroma when smashed. These leaves are highly valued for their ability to enhance a delightful flavor and fragrance to a wide array of culinary creations including variety of foods, baked goods, and drinks. Moreover, their high vitamin C concentration provides extra nutritional value to diets, contributing to overall health and well being. (Dubey et al., 2016)

Chemical Constituents and their activity:

Widely cultivated across the globe, Citrus karna Raf. is primarily grown for its peel, juice, and pulp, which find extensive applications in the food and beverage industry. Citrus karna Khatta is rich in bioactive compounds, including essential oils, flavonoids, phenolic compounds, and vitamin C, which contribute to its pharmacological properties. Essential oils extracted from Citrus karna Khatta are known to possess antimicrobial, antioxidant, anti-inflammatory, and insecticidal activities. These oils are often used in

aromatherapy and topical applications for their therapeutic benefits. Flavonoids and phenolic compounds found in Citrus karna Khatta exhibit antioxidant and anti-inflammatory effects, which may contribute to its potential in preventing or managing various diseases, including cardiovascular disorders and cancer. The high vitamin C content of Citrus karna Khatta enhances its nutritional value and contributes to its immune-boosting properties. Pharmacological studies have shown that extracts from Citrus karna Khatta may have neuroprotective effects, potentially offering benefits for cognitive function and neurological health. (Morales et.al., 2023).

Pharmacognostic and morphological traits:

The pharmacognostic and morphological traits of this citrus variety play a crucial role in its commercial cultivation and utilization. Understanding the distinctive characteristics of Citrus karna Raf., both in terms of its pharmacognosy (study of medicinal properties of plants) and morphological traits, facilitates its identification, cultivation, and utilization in various industries. This comprehensive knowledge serves as the foundation for further exploration into the pharmacological activities and potential health benefits of Citrus karna Raf., contributing to its continued importance in global agriculture and commerce. (Smeriglio et al., 2022).

Morphological characteristics of Mandarin Trees(Citrus reticulate Blonco)

Mandarin trees (Citrus reticulata Blanco) are small to average-sized, evergreen shrub that develop in a spreading way and typically stretch out a height of about 6 to 15 feet (2 to 5 meters). They have a rounded canopy with slender branches enfold in thorns. The leaves are glossy green, elliptic or lanceolate in shape, and have slightly serrated borders. They are spread out alternately on the branches and give out a fragrant sweet limetta scent when squeeze. White, fragrant blossoming leaves that are frequently single or in clusters append to the tree's aesthetic appeal.

Fruits Characteristics of Mandarin Trees

Mandarin trees give rise to small, fragrant clourless white flowers with pentamerous. The flowers are typically solitary or arranged in tiny clusters at the leaf axils. The fruit of the Mandarin is perhaps the significant distinctive feature. The fruit is a typical resentful berry that is easy to fragment and peel. It has an orange, yellow, or green-colored husk depending on the variety and mature. Mandarin fruits are segmented into smoothly separable sections, and the flesh is juicy, sweet that is thin, soft, easily

peelable peel and reticulated and usually seedless or contains very some seeds. The root arrangements of a Mandarin tree is generally shallow and scattering. Mandarins are a popular choice for fresh consumption because of their delightful, juicy pulp, which is frequently seedless. If present, seeds are small, oval-shaped, and pale in color. This fruit's scale can be augment to herbal to decoction help with coughing, and the essential oil is oftenly used for essence or aroma. (Qureshi et al., 2023).

B. Pseudolimon Tanaka(Galgal)

Morphological Characteristics

Citrus pseudolimon Tanaka is a small to medium-sized evergreen tree with a spreading growth appearance, reaching height of around three to six meters. Leaves are shiny greenish, elliptical to oval in shape with finely toothed margins and placed unevenly in the branches. They emit sharp citrus fragrant blossoms that are typically white or light purple in hue. They produce fragnant white flowers with five petals similar to other citrus varities. It is sometimes, referred to as Galgal, will resemble a modified berry with strong citrus characteristics. The fruit also small to medium-sized like his tree. They have approximately the size of a lemon nevertheless often slightly become flat. It has a thick, aromatic husk that ranges in color from green to yellow-orange when ripe. The flesh is segmented, juicy, and contains numerous ovules. Fruits are valuable for their distinctive flavor, which is extremely aromatic and acrid, with a unique floral note. Essential oils may be present in the peel, which have an aroma. When mature, the fruit can have a variety of colors, usually has a characteristic yellow flavor. Though they can vary, the tree's size, leaves, flowers, and fruits are usually within the range of usual citrus species. (Deb et al., 2022).

Characteristics and Traditional Uses of Cirtus pseudolimon Tanaka

The rind of the Citrus Pseudolimon Tanka fruit is chunky and bumpy, with a irregular texture compared to other citrus fruits. This texture fabricate it ideal for grating or zesting, as it produce flavorful zest lacking incorporating bitter colourless pith. It typically, mature in late autumn or early winter, depending on the region. They are possessed for their aptness to withstand chilly temperatures and are often harvested after the first ground frost, which enhances their flavor. It holds traditional significance in Japan, where it is used in various culinary traditions and festivals. It is particularly associated with the

winter season and is used in hot baths during the winter solstice for its aromatic and remedial properties. (Prasanna et al., 2023).

Morphological Characteristics of Grapefruits (Citrus paradise var.Foster)

A medium-to-large evergreen tree with a rounded growth pattern. The fragrant white blooms, which are often solitary and glossy, alternately arranged leaves. The enlarged berry, known as the grapefruit, has a thick skin and a spherical to slightly flattened shape. The fruit can range in color from yellow to pink or red, and the segmented pulp has a bittersweet flavor. Citrus varietals are numerous, with grapefruits being one of the fruits with a distinct taste (Singh et al., 2023).

Each might have distinct tastes, qualities, and even therapeutic potential due to the presence of particular chemical markers or chemicals. Like many citrus fruits, Kharna khatta probably contains some citric acid, which adds to its distinct acidic qualities and sour flavor.

Chemical compostituents and Pharmacological Properties of Citrus fruits

Citrus fruits include a class of chemicals called limonoids, which have anti-inflammatory, antioxidant, and anti-cancer effects. Certain limonoid chemicals that may be present in kharna khatta contribute to its therapeutic efficacy. Its peel contains vital oils that add to its taste and scent. These oils could contain substances like citral, limonene, and linalool. Galgal is highly valued for its fragrant peel, which has essential oils with a distinct aroma. Galgal's bright, flowery scent can be attributed to the presence of chemicals like limonene, citral, the oil, and linalool in its essential oil composition. Citrus fruits contain a wide range of plant components called flavonoids, which have anti-inflammatory and antioxidant qualities. Certain flavonoids, such naringin and hesperidin, may be present in galgal, which adds to the plant's possible health advantages. Vitamin C, an important ingredient with antioxidant qualities that promotes collagen formation, immunological function, and skin health, is probably abundant in galgal. The Foster type of grapefruits is well-known for having a high concentration of flavonoids, namely naringin and hesperidin. These substances have been investigated for their possible antioxidant and cholesterol-lowering properties in addition to adding to the grapefruit's bitter flavor.Pectin, one kind of soluble fiber found in grapefruits, has been linked to improved digestive health, blood sugar regulation, and weight management.Like other citrus fruits, grapefruits' peel contains essential oils that enhance its flavor and scent. These oils could include substances like pinene, myrcene, and limonene. (ALI et al., 2024).

Culinary and Medicinal Uses of Citrus Fruits

Because of its sour taste, kharne khatta is mostly employed in culinary applications. In Indian cooking, it's frequently used to impart sourness to foods like sauces, chutneys, curries, and drinks like lemonade. Kharna khatta is utilized as a help to the digestive system in traditional medical systems such as Ayurveda. It is said that taking lemon juice or water with lemon may increase the production of digestive enzymes, encourage the flow of bile, and relieve indigestion and bloating symptoms. Kharna khatta is a great natural preservative due to its acidic composition. Lemon juice is frequently used to stop food from oxidizing and spoiling, keeping vegetables from becoming brown or sliced fruits from browning. Because lemon juice is astringent and antibacterial, it is occasionally administered directly to the skin. (Sidhu et al., 2024)

Galgal is highly valued for its distinct flavor and scent in East Asian cooking. It is used to sauces, salads, marinades, desserts, and alcoholic beverages to give them a zesty, flowery touch. Owing to its elevating and relaxing properties, the fragrant essential oil that is produced from galgal peel is utilized in aromatherapy. It is said to induce relaxation and improve mental health by easing tension, anxiety, and exhaustion. Because of its fragrant and medicinal qualities, galgal is historically used in hot baths at the winter solstice in Japan. It is said that the scent of citrus will help relieve the symptoms of a cold and assist the body and mind relax. (Zibaee et al., 2020).

Health Benefits and Therapeutic Potential Of Grapefruit

Because of their high fiber content and low calorie count, grapefruits including the Foster variety are frequently a part of regimens designed for weight reduction and detoxification. It is thought that consuming grapefruits or grapefruit juice can help with digestion, blood sugar regulation, and satiety. According to certain conventional wisdom, eating grapefruit may help decrease cholesterol and lower the risk of heart disease. This is ascribed to substances contained in grapefruit, such as naringin and hesperidin, which have been investigated for possible effects on cholesterol. Many civilizations like grapefruit juice as a cool drink. It is frequently had for breakfast or as a refreshing beverage on hot days. In certain traditional treatments, grapefruit juice is combined with other components to make tonics or elixirs that are meant to improve health. (Calvez et al., 2020).

Bioactive Compounds and Pharmacological Activities of Citrus Plants

Citrus plants are known for their diverse pharmacological activities due to their rich content of bioactive compounds. Karna Raf. is rich in photochemicals, essential oils, minerals and phenolic admixture. The high significance of vitamin C and flavonoids in Karna Raf. give to its powerful antioxidant properties, which help in counteracting free radicals and preventing oxidative stress-related diseases. By blocking inflammatory mediators including prostaglandins and cytokines, flavonoids and phenolic materials demonstrate their anti-inflammatory properties. Karna Raf has essential oils and other phytochemicals that have been shown to be effective against a range of bacterial and fungal diseases, making it a valuable tool for the treatment of illnesses. By lowering cholesterol, avoiding lipid peroxidation, and enhancing blood vessel function, the antioxidant and anti-inflammatory qualities support cardiovascular health. High concentrations of limonoids, flavonoids, and essential oils are characteristics of galgal. Because galgal has a high quantity of flavonoids and limonoids, which defend cells from damage caused by oxidation, it has beneficial antioxidant qualities. Galgal has considerable antibacterial action toward a variety of pathogenic microorganisms, which makes its essential oils and limonoids valuable for food preservation and illness treatment. By preventing the synthesis of mediators of irritation, the naturally occurring compounds in galgal may lessen inflammation. The potential cytotoxic properties of galgal limonoids, such as their ability to induce apoptosis in cancer cells and limit the formation of tumors, have been evaluated. (Saini et al., 2022).

C. Paradisivar. Foster:

Chemical constituents and Pharmacological Activities of Grapefruits

The grapefruit variety has a significance amount of essential fatty acids, lycopene, vitamin C, naringin, and naringenin. Rich in antioxidants vitamin C, naringin, and lycopene, it has powerful antioxidant qualities that help prevent damage from oxidation and related illness that last. It was recently showed that naringin and naringenin decrease swelling by blocking signicant inflammatory mediators and pathways. Grapefruit's fragrant oils and other elements have antibacterial characteristics that can tackle a variety of ailments, such as fungal organism and bacteria. Compounds found in grapefruits contribute to improved lipid composition, lower cholesterol, and improved heart wellness in general. By triggering cell death, preventing cell proliferation, and disrupting the signaling pathways of cancer cells, naringin and naringenin possess anticancer effects. Because grapefruit influences lipid metabolism and glucose

control, eating it has been linked to weight loss and more effectively metabolic health. (Murthy et al., 2020).

Bioactive Chemical Constituents in Citrus Fruits Peels

Bioactive flavonoids found in citrus fruit peels, such as quercetin, hesperidin, and naringin, have demonstrated promise in the treatment of diabetes and obesity. These substances control lipid metabolism, prevent adipogenesis, and boosts insulin sensitivity. By removing and using these flavonoids, we may be able to develop new treatments for diabetes and obesity that are also in line with sustainable methods. It is now feasible to extract these molecules with great efficiency and purity because to developments in extraction methods and computer-aided drug discovery. In the pharmaceutical and nutraceutical sectors, this strategy supports environmental sustainability and public health in line with the principles of the circular economy. (Lu et al., 2023).

Unique Bioactive Combinations in Citrus Species

Several kinds of citrus are distinguished by their distinct unique combinations of bioactive substances, which enable their varied medicinal actions. These include positive aspects related to metabolic processes, anticancer, anti-inflammatory, antibacterial, and cardioprotective wellness. These citrus species are valuable for future scientific academic research as well as medicinal uses given to their rich abundance of flavonoids, essential oils, vitamins, and other metabolites. Antioxidant and anti-inflammatory qualities are present in all. These characteristics could help lessen the oxidative stress and inflammation linked to metabolic disorders. Furthermore, may be used in food or topical treatments, as well as incorporated into lifestyle practices like aromatherapy, for the purpose of preventing and treating metabolic illnesses such as hypertension and Diabetes. (Moraes et al., 2024).

Literature Review

1. Qureshi et al. (2023) studied the effects of different root stock on their development, yield, and nutritional values of citrus a member cultivars, concentrated on their mechanical and biological

features. With an focus on resistant to diseases, adaptability to drought, productivity of the plant, and the relation between root stocks and branch cultivars and makes plans for the most effective citrus growing methods. Research databases were perused in order to find out how differing root stock influence the growth rate of citrus scion different varieties both in Pakistan and all over the world. They rejected articles that contained actual information on rootstock-scion interactions, however they did include articles evaluating and research studies. Citrus scion performance indicators data were gathered from a variety of research, taking into account factors like as design, sample sizes, locations, and climatic circumstances. These indicators included vegetative growth, mineral intake, physiological performance, and reproductive growth. While comparative research revealed variances and similarities in rootstock-scion pairings under uniform climatic and soil conditions, the review used qualitative synthesis to find common themes and patterns. The writers assessed the caliber of research on Pakistan's citrus crop, pointing out any biases and shortcomings. They also talked on how rootstocks affect performance measures in Pakistan's soil and climate, highlighting how important rootstocks are to the development of the area. Qureshi offers suggestions for choosing rootstocks that would maximize the performance of citrus scion varieties in Pakistan. It points out gaps in the literature and makes recommendations for further study, including studies that are region-specific and long-term on the compatibility of rootstocks and scions. The methodical approach guarantees a thorough comprehension of the function of rootstocks in Pakistani citrus farming. He focuses on how various citrus scion cultivars are impacted by their rootstocks. There are a few holes in the study, though. First off, the study takes a more worldwide approach, taking into account the importance of citrus agriculture in various geographical areas. Second, neither the historical distribution nor the nutritional advantages of citrus fruits are discussed in the study. Thirdly, a historical perspective on the evolution or dissemination of citrus growing techniques is lacking from the research. Fourthly, the study makes no mention of how consuming citrus fruits may affect public health. Lastly, a thorough economic study of the citrus business, taking into account market dynamics and financial difficulties, is lacking from the research. A more thorough understanding that takes into account historical patterns, nutritional advantages, consequences for public health, and the global economic environment is required to close these gaps. This would provide a more comprehensive knowledge of the importance and difficulties associated with growing and consuming citrus globally.

2. Sharma et al., (2015) studies to analyze the impact of different rootstocks on the physiological growth and development of ‘ March Seedless’ and ‘ Redblush’ grapefruits varities over damp circumstances in North India is complete and particular. The scholars decided a range of rootstocks, including 'Rough Lemon,' 'Billikhichli,' 'RLC-4,' 'Troyer Citrange,' 'Attani-2,' and 'Karna Khatta,' to examine their impact on several physiological parameters. Key metrics such as photosynthetic rate, stomatal conductance, Relative Water Content (RWC), Excised Leaf Water Loss (ELWL), and antioxidant enzyme activities (Superoxide Dismutase (SOD), Peroxidase (POD), Glutathione Reductase (GR), and Catalase (CAT)) were systematically measured. The study also assessed total soluble protein concentrations, which are indicative of the plant’s metabolic health and stress response capabilities. Experimental plots were established under uniform humid conditions to minimize environmental variability. Standard horticultural practices were followed to ensure consistent plant growth and health across different rootstock treatments. Detailed statistical analyses were conducted to interpret the data, providing insights into the physiological interactions between the rootstocks and the scion cultivars. This methodological rigor enabled the identification of rootstocks that optimize water uptake, enhance photosynthetic efficiency, improve water retention, and bolster antioxidant defenses, thereby informing best practices for citrus cultivation in varying environmental contexts. In this research, Rootstocks significantly impact citrus plant development, including stress resistance, growth, reproductive development, and fruit quality. Selecting compatible rootstocks for specific zones can enhance fruit production and quality, enhancing citrus cultivation efficiency.

3. Singh et al. (2022) studied on genetic diversity, heritability, and genetic advancement in mandarin genotypes is essential for crop development and breeding in the subtropical environment of India. It makes use of heritability estimations, measurements of physical traits, cluster analysis, and phenotypic and genotypic studies. The dominance of some features over environmental circumstances is indicated by their high heritability, such as rootstock diameter, scion diameter, fruit weight, and seed weight. The physiological effects of several rootstocks on the grapefruit cultivars 'Marsh Seedless' and 'Redblush' in North India are investigated in this study, with particular attention to photosynthetic rate, stomatal conductance, and antioxidant enzyme activities. The target regions and research approaches used in the studies on grapefruit

cultivars and mandarin genotypes vary. Research on mandarin concentrates on genetic diversity and its consequences for breeding, whereas studies on grapefruit highlight physiological reactions. Combining physiological evaluations with genetic analysis may yield more insightful breeding plans.

4. Grotewold et al. (2006) studied on citrus juices changed as interest in their flavonoid content—which offers advantages for both biology and mechanics—grew. Citrus juices are full in flavonoids, which have anti-inflammatory, antioxidant, and anticancer activities. Flavonone-O-glycosides and flavone-O- or -C-glycosides are particularly prevalent in these compounds. Juices that are hand-extracted maintain their original phytochemical makeup, whereas industrial processing may cause some chemicals to be reduced or destroyed. Different citrus cultivars have unique profiles of flavonoids. Numerous studies have been conducted on flavonoids in citrus juices utilizing techniques including NMR spectroscopy, HPLC, and MS. With the use of these methods, flavonoid components may be identified and measured, allowing for a thorough knowledge of their content and distribution in various citrus species. Citrus juice flavonoid analysis includes compound extraction, HPLC chromatographic separation, detection, and quantification using NMR or MS. Comparing the profiles of several citrus species helps to understand how industrial processing and extraction techniques affect the final product. There is a large disparity in the research on citrus rootstocks and cultivars; the former studies physiological characteristics like photosynthetic rate and antioxidant activity, while the latter focuses on chemical composition and health advantages. Citrus flavonoid research mostly focuses on post-harvest processing and extraction techniques, with little investigation of growing techniques and environmental factors. A thorough understanding of the flavonoid content and health advantages of citrus fruits might be obtained through research on rootstock selection, post-harvest processing, and cultivation techniques. This knowledge could then be used to breeding and cultivation tactics aimed at improving crop productivity and nutritional quality.

5. Karthikeyan et al. studies on C. aurantium collect traditional information about its therapeutic benefits by chemical analysis, pharmacological testing, and ethnobotanical surveys. While pharmacological research uses animal models, cell culture tests, and clinical trials to assess the

biological activities of the plant's bioactive chemicals, chemical analysis finds the molecules in the plant. The chemical makeup and pharmacological characteristics of C. aurantium are the main subjects of research, with a focus on traditional therapeutic usage. Contrarily, research on citrus juices focuses on biochemical and nutritional factors. Nonetheless, little is known about how farming methods and environmental factors impact the chemical makeup and therapeutic qualities of the plant. The effects of post-harvest processing, environmental factors, and growing techniques on the chemical makeup and pharmacological characteristics of C. aurantium should be investigated in future studies. Combining contemporary methods with ethnomedical knowledge may maximize the therapeutic and nutritional advantages, resulting in novel approaches to the breeding and processing of citrus plants.

6. Barbora et al., (2020) studied an eco-geographic survey are genotype collection, characterisation, and preservation steps in the study of citrus diversity in northeastern India. It assesses physio-chemical characteristics, fruit output, and plant growth. At the Citrus Research Station, the gathered genotypes are cultivated in a germplasm block and evaluated for rootstocks or commercial cultivation. In order to find genotypes that are commercially viable, research on citrus diversity in northeastern India concentrates on preserving and assessing wild and semi-wild genotypes. Research on Citrus aurantium and citrus juices use sophisticated analytical techniques to assess their chemical makeup, pharmacological characteristics, and health benefits. There has been little research on citrus variety in northeastern India that looks closely at genetic diversity and conservation issues. Instead, it focuses on the morphological and physiological characteristics of genotypes and their chemical composition and pharmacological characteristics. To improve citrus species conservation and exploitation for agricultural and medicinal reasons, future research should integrate genetic diversity and conservation with chemical and pharmacological assessments. By analyzing bioactive substances and estimating possible health benefits, this all-encompassing method would guarantee the preservation of genetic variety and provide well-informed breeding and production practices.
7. Chandal et al. (2022) studied on the hydrocolloid pectin, which is present in apples and citrus fruits, has several uses and is a significant element in the food, medicine, and packaging sectors. It serves as an emulsifier, thickener, and ingredient in low-calorie meals such as jams and jellies. It is utilized in the pharmaceutical industry for medications, coatings, edible films, paper

alternatives, and foams. The extraction of pectin from unconventional sources and fruit waste is the main focus of current research. Pretreatment of source materials, ideal extraction conditions, purification by filtering, precipitation, and drying, and characterization using methods such as FTIR, HPLC, and rheological tests are all part of the process of extracting and characterizing pectin. Esterification, molecular weight, and gelling qualities are determined by these investigations, which are essential for applications. Current research investigates chemical and enzymatic changes for particular industrial applications. Pectin research is concentrated on its extraction, characterisation, and multipurpose usage in many sectors. Research on citrus diversity is primarily concerned with conservation, genetic diversity, and assessing features for commercial and breeding uses. On the other hand, little is known about the effects of genetic variety and various production techniques on pectin output and quality. To maximize the quantity and quality of pectin derived from various sources, an integrated strategy integrating genetic, agronomic, and biochemical investigations is required. Future studies should examine how cultivation techniques and genetic variation affect the quantity and quality of pectin in various citrus genotypes. Combining agronomy, biochemistry, and genetic conservation might improve extraction methods and help sectors that depend on high-quality pectin by increasing pectin output and functioning.

8. Deb, et al. (2022) study on India's native citrus indica is seeing a population decrease as a result of urbanization, climate change, agricultural pressures, and geographic limitations. Seed propagation and survival are impacted by the fruit's shape and juice content. Customers' distaste for the fruit's flavor, despite their reasonable appreciation of its color, scent, and texture, has led to its decreased cultivation and endangered status. Conservation initiatives may be aided by knowledge of its possible advantages and financial worth. Field surveys, morphological and biochemical characterisation, sensory assessment, and interviews with locals were all part of the Citrus indica research. It examined fruit size, pH, TSS, juice content, and tasted the juice in addition to documenting the present Citrus indica trees in the Nokrek Biosphere Reserve. Insights on growth, customer preferences, and decreased cultivation were obtained through interviews. Citrus indica research focuses on morphological, biochemical, and sensory assessments in order to conserve the species and comprehend the elements that influence its endangered status. Studies on the extraction of pectin concentrate on the characteristics, methods, and uses of the extracted product; genetic diversity and conservation

of the citrus species are not given as much attention. Citrus species conservation (Citrus indica, for example) and their potential as sources of pectin extraction might be combined in future studies. Studies on genetics and agronomy, biochemical analysis, promoting conservation and usage, and community involvement would all be necessary for this. Through the promotion of economic value and awareness among local populations, this method has the potential to improve both biodiversity preservation and sustainable industrial uses .

9. Deng et al. (2020) studied on modern citrus species originated in Eastern and Southern Asia, where citrus domestication and history began. Citrus is important; ancient agriculture in China, Japan, and India attests to this. Asian citrus germplasms' genetic diversity has been uncovered by molecular biology techniques, offering new perspectives on their genetic make-up and evolutionary background. The enhancement of crops and breeding depend heavily on this genetic variety. Using an interdisciplinary approach that incorporates historical inquiry, botanical discovery, and genetic biology, the study examines the history of citrus domestication. Citrus cultivation, distribution, and genetic diversity in Asia are traced using morphological studies, field surveys, molecular markers, and data analysis, as well as ancient writings. The research looks at the history and domestication of citrus with an emphasis on genetic diversity and dispersion. Along with examining risks, morphological and biochemical traits, socioeconomic variables influencing agriculture, and possible economic rewards, it also looks at citrus germplasms and their conservation status. Future research should combine genetic and historical knowledge from domesticating oranges with endangered species protection plans. This covers thorough genetic research, planning for conservation, and the use of genetic variety in breeding initiatives. Furthermore, promoting sustainable usage and preservation may be accomplished by increasing knowledge of the historical significance and genetic worth of endangered citrus species. Future generations will be able to benefit from and preserve priceless citrus germplasms thanks to this comprehensive strategy.

10. EI Gengaihi et al. (2020) studied as citrus wastes include bioactive chemicals, they may find use in pharmaceuticals. Volatile oil components may be identified with the use of GC/MS analysis and PCR-based DNA fingerprinting. While lemon peel oil has cytotoxic and antimicrobial properties against liver and breast cancer cell lines, grapefruit peel and lemon leaf oils

demonstrate antimicrobial and cytotoxic properties. Molecular biology methods, chemical analysis, and biological tests were employed in the citrus waste research. Five citrus trash species were used to collect DNA fingerprints, while peels and leaves were used to recover volatile oils. Disc diffusion techniques and MTT tests were used to evaluate the oils for antibacterial activity and cytotoxicity against pathogenic bacteria and fungi. Using genetic characterisation, chemical composition, and biological activities, the study investigates the medicinal potential of citrus wastes. This is in contrast to studies on citrus domestication and genetic diversity, which concentrate on germplasm preservation and evolutionary importance. The medicinal potential of citrus wastes should be combined with historical and genetic insights from domestication research in future investigations. In order to achieve this, it is necessary to link genetic diversity data with biochemical properties, carry out in-depth phytochemical analyses, support the preservation of genetically diverse citrus species, and foster interdisciplinary research to fully investigate the potential of citrus species and their waste products in drug discovery.

11. Benedetto et al. (2023) studied on the citrus, a Rutaceae plant, has been extensively utilized in conventional medical practices for a century due to its wide beneficial effects. Its abundant vitamins, flavonoids, and macronutrients provide it antibacterial, anti-inflammatory, and antioxidant qualities. Flavonoids, coumarins, terpenes, and phenolic acids are abundant in Citrus medica. These substances have broad-spectrum antibacterial and antiviral activities, suppress inflammatory mediators, and have antioxidant and anti-inflammatory actions. They also possess neuroprotective, anticancer, and antidiabetic qualities. In addition to preventing oxidative damage and neurodegenerative illnesses, flavonoids and terpenes also limit inflammatory mediators and neutralize free radicals. Using the PubMed and Scopus databases, the study focuses on a comprehensive assessment of the phytochemical composition and biological characteristics of Citrus medica Linn. In order to determine connections between species, describe volatile oils, and assess their cytotoxic and antibacterial properties, it also looks into the chemical analysis of volatile oils in citrus wastes. To find special chemicals and interactions, future research might compare the phytochemical compositions of Citrus medica with other citrus species, including citrus wastes. Integrated biological research might pinpoint common bioactive substances and the underlying processes. Genetic research might examine genetic

variation among populations of C. medica. Sustainable usage of citrus wastes might support medicinal potential and long-term applications.

12. Dongre et al. (2023) studied on the sweet oranges, or Citrus sinensis, are a plant that is high in flavonoids, essential oils, and phenolic acids. Due to their antioxidant qualities, these substances lessen oxidative stress and neutralize free radicals. Antibacterial, antifungal, and antiviral qualities can be found in essential oils, especially the peel. Citrus sinensis is a fruit that contains anti-inflammatory, antibacterial, antifungal, antidiabetic, and hypocholesterolemic qualities. Its extracts have been shown to help control weight by controlling lipid metabolism and preventing fat from accumulating. Using a systematic literature review method, the study focuses on the phytochemical composition and biological aspects of Citrus sinensis. Additionally, it explores the biological properties of citrus waste products by assessing the antibacterial and cytotoxic properties of volatile oils and identifying genetic links across species using PCR-based DNA fingerprinting. Future investigations might combine molecular approaches with systematic reviews, do comparative analyses, incorporate biological tests, and investigate the sustainable use of citrus waste products for medical applications.

13. Lu et al. (2023) studied on the citrus fruits are well known for their abundance of nutrients and health advantages. Water, carbohydrates, vitamins, minerals, and dietary fibers are all present in them and are necessary for proper hydration and metabolic functions. Bioactive substances that provide protection against a range of illnesses include flavonoids, essential oils, carotenoids, limonoids, and synephrines. Additionally, potassium, calcium, and magnesium—all important elements for cardiovascular health—are included in these fruits. Flavonoids, essential oils, carotenoids, limonoids, and synephrines are just a few of the substances found in citrus fruits that have anti-inflammatory, antioxidant, and anticancer properties. These substances enhance cardiovascular health, lower inflammation, treat ailments including arthritis, and prevent cancer. Additionally, they strengthen the immune system, support healthy digestion, avoid constipation, and guard against infections thanks to their high vitamin C content. Citrus fruits are generally very beneficial to health. Citrus sinensis, a citrus fruit, is the subject of this study along with its phytochemical makeup and biological properties. It makes use of a thorough analysis of nutrients and bioactive substances found in a variety of citrus species as well as

methodical literature research approaches. Comparative analysis, integrated methods, investigating understudied species, and using molecular biology techniques might all be beneficial for future study. The potential of citrus fruits, especially Citrus sinensis, may be better understood and used for a variety of health-promoting applications by filling in gaps and combining varied research methodologies.

14. Indriyani et al. (2023) studied on the citrus fruits are well known for their abundance of nutrients and health advantages. Water, carbohydrates, vitamins, minerals, and dietary fibers are all present in them and are necessary for proper hydration and metabolic functions. These fruits are abundant in bioactive substances that provide protection against a range of illnesses, including carotenoids, synephrines, flavonoids, and essential oils. These substances have anti-inflammatory, anti-cancer, and antioxidant properties. Additionally, they support intestinal health, strengthen the immune system, control blood pressure and cholesterol, and treat illnesses like arthritis. Additionally, the high vitamin C concentration helps to prevent infections. This thorough analysis of Citrus sinensis emphasizes the plant's biological properties and phytochemical makeup, as well as any possible medical applications. The study makes use of a comprehensive summary of nutrients and bioactive chemicals found in different citrus species as well as systematic literature review approaches. Comparative analysis, integrated methods, investigating understudied species, and using molecular biology techniques might all be beneficial for future study. The potential of citrus fruits, especially Citrus sinensis, may be better understood and used for a variety of health-promoting applications by filling in gaps and combining varied research methodologies.

15. Lu et al. (2023) studied the citrus peels, being high in bioactive flavonoids, may offer therapeutic benefits, especially in controlling diabetes, lowering obesity, and regulating lipid metabolism. Hesperidin, naringin, and quercetin are important flavonoids that are present in citrus peels and have potent anti-inflammatory, lipid-lowering, and antioxidant effects. By upregulating genes involved in fatty acid oxidation and downregulating those involved in lipid synthesis, these flavonoids limit adipogenesis, lowering the storage of fat, and improve lipid metabolism. Additionally, they offer anti-inflammatory and antioxidant properties that lower oxidative stress and shield against long-term illnesses like diabetes. Citrus peels contain bioactive chemicals that

may be extracted and used to reduce environmental impact and improve sustainability. The research focuses on the antiobesity and antidiabetic properties of the bioactive flavonoids found in orange peels. By advocating for their usage in the pharmaceutical business and showcasing their medicinal potential, it seeks to advance a circular economy. The report also emphasizes how repurposing citrus trash may assist the environment by encouraging sustainable habits and a circular economy. While the other studies include a wide variety of health benefits without a special focus on metabolic illnesses, the treatment focus is on obesity and diabetes. Subsequent investigations ought to bridge these gaps by merging thorough phytochemical analysis with creative computational methods. (Lu et al., 2023).

16. Elhawary et al. (2024) studied on many bioactive substances, including monoterpenes, sesquiterpenes, and flavonoids, are present in citrus essential oils, which are derived from different portions of the citrus plant. These oils offer a variety of biological properties, such as antibacterial, antidiabetic, anti-inflammatory, and antioxidant properties. Citrus aurantium essential oils have neuroprotective, antidiabetic, and antioxidant properties because they include monoterpenes and sesquiterpenes. Citrus oils from citrus sinensis and citrus medica Linn. offer antiviral, antibacterial, anti-inflammatory, and antihyperglycemic qualities. Utilizing citrus waste—peel and fruit segments, for example—aligns with the concepts of sustainability and the circular economy while producing important medicinal chemicals. Citrus leaf essential oils were extracted using three different methods: steam distillation, hydrodistillation, and microwave-assisted distillation. The production and content of the oils were impacted by the extraction techniques. The chemical composition was examined using Gas Chromatography-Mass Spectrometry (GC/MS) and Gas Chromatography with Flame Ionization Detection (GC/FID). A total of 35 volatile chemicals were found and measured. The study highlighted the financial and environmental advantages of using citrus trash for pharmaceutical uses by focusing on the bioactive flavonoids found in citrus peels. The other study compared extraction methods and highlighted the chemical makeup and bioactivities of Citrus aurantium leaf essential oils. With an emphasis on citrus peel flavonoids and essential oils from citrus aurantium leaves, the research investigate the health advantages of bioactive substances in citrus plants. Computational methods and phytochemical analysis should be combined in future study.

Research strategy

This chapter provides a systematic analyses of the literature on pharmacological activities of distinct citrus plant varieties i, e. karna Raff. (Kharna khatta), C. pseudolimon Tanaka (Gal gal), and C. paradisi var. Foster" **(**Rutaceae, flavonoids) for managing obesity and diabetes**.** It includes methods for locating information, looking at selection criteria, extracting and analyzing statistics, visually appealing assessment procedures, and synthesizing statistics. The review seeks studies published in English between 2015- 2023. It was carried out on many databases. During this extensive literature search, a number of reliable databases were thoroughly examined, including PUBMED, LILACS, SCIELO, Science Direct, and Web of Science. The focus was on ethnobotanical, ethnopharmacological, biological, and phytochemical data, with a special emphasis on any possible therapeutic effects. The search utilized diverse keywords to identify various plant genera, phytochemicals, and flavonoids in the group of Rutaceae family, capturing various studies on their pharmacological potential. The study used an extensive article selection procedure to make sure that only good and relevant papers were included. A standardized data extraction form was utilized to obtain pertinent data from the studies that were included. An essential part of the methodological framework was quality evaluation, which assessed the research' reliability and rigor. The selected publications were organized and categorized based on key parameters, providing insights into trends and patterns in research on Rutaceae flavonoids, their global distribution, and their biological activities. A wealth of information on the pharmacological properties and possibilities for creating new therapeutic agents is provided by this systematic study of flavonoids belonging to the Rutaceae family. This methodology provided valuable insights into the curative value of citrus plant types for treating diabetes mellitus and obesity by ensuring a transparent and rigorous approach.

Table 1: Data basis along with their description and reasoning

Sources	Description & Reasoning

PUBMED	Because of its extensive coverage and peer-review research on the pharmacological properties of citrus plant types, PUBMED is used.
LILACS / SCIELO	LILACS utilized because to its extensive collection of research from Latin America and the Caribbean, which gave unique regional views on the pharmacological properties of citrus plant varieties.
Science Direct	Because of its extensive library of excellent, reviewed scientific and technical research materials that offer in-depth understanding of the therapeutic effects of different citrus plant kinds.
Web of Science.	Its extensive interdisciplinary library of influential research papers, it utilized to provide comprehensive coverage of studies on the pharmacological activity of citrus plant species.

Science Direct, Web of Science, LILACS, SCIELO, and PUBMED are the five databases that were used for this literature review. The reason these databases were selected is because they offer access to relevant publications across a wide variety of disciplines in the biomedical sciences, life sciences, and healthcare. After conducting a thorough search that produced a large number of results, the inclusion and exclusion criteria suggested by Moule (2018) were applied to further concentrate the results in order to guarantee the findings' application and precision.

The search results were further filtered using Boolean Operators. The researcher used Boolean operators such as "AND," "OR," and "NOT" to combine or remove certain nouns and phrases. The search yielded fewer irrelevant items because of its tighter focus. But it's important to remember that, as Aveyard (2014) points out, it might be possible to use the "NOT" operator to remove certain phrases since it can unintentionally eliminate relevant articles.

Table 2: An illustration of the particular search approach applied in this literature review to find appropriate articles

AND	OR	NOT
CITRUS PLANT VARITIES		
Citrus	"Citrus" OR "Citrus Plants" OR "Citrus species" OR "Citrus varieties" OR "Citrus types"	NOT "mango" NOT "banana" NOT "grapes" NOT "tomoto"
PHARMACOLOGICAL ACITIVITIES		
Pharmacological	"pharmacological activities" OR "pharmacological effects" OR "pharmacological properties"	NOT "horticulture" NOT 'food science"
CHEMICAL CONSTITUENTS		
Compounds	"Flavonoids" OR "Limoniods" OR "Essential Oils" OR "Vitamin C"	
FUNCTION AND PROPERTIES		
Benefits	"Antioxidant" OR "Anti-inflammatory" OR "Anticancer" OR "Antimicrobial" OR "Health Benefits"	
Applications		
Applications	"therapeutic" OR "Medicinal" OR "pharmaceutical" OR "Clinical"	NOT "industrial" NOT "cosmetic" NOT "perfume"
BIOLOGICAL ACTIVIES		
Bioactivity	"bioactivity" OR "biological activity" OR "mechanism of	

	action" OR "mode of action"	
NON-SCIENTIFIC SOURCES		
		NOT "blog" NOT "magazine" NOT "news articles" NOT "advertisement"
OTHER CITRUS USES		
		NOT "food preservatives"

With regard to the pharmacological properties of citrus plant types, this table is intended to help researchers organize and carry out thorough literature searches. In order to assist filter and optimize search queries for accurate and pertinent results, it groups important search phrases into three categories: AND, OR, and NOT. The words to look for have important ideas about the research topic. Other phrases include similar words to make the wider and cover different terms in the literature. This helps get a lot of relevant studies. Terms to exclude make sure to filter out unrelated studies and keep the search results specific and on point.

The table has sections like kinds of citrus plants, what they do pharmacologically, specific parts, health perks, ways to use them, and functions in biology. There's also a part to exclude non-science stuff about citrus. Each section has words to look for, other similar words, and words to avoid. For instance, under citrus plant varieties, words to look for are "Citrus," similar words are "Citrus plants" and "Citrus species," and words to avoid are things like "mango" and "banana." This helps search for articles more effectively.

Searching for pharmacological activities needs words like "Citrus" and "pharmacological activities," similar words such as "Citrus species" and "pharmacological effects," and avoiding terms like "food science." Searches for specific compounds and applications use the same structure to find relevant studies and exclude irrelevant data. The table is made to make doing literature reviews easier and improve research on the pharmacological activities of citrus plan.

Chapter 4: Results

Identification of new studies via databases and register

Identification of new studies via other methods

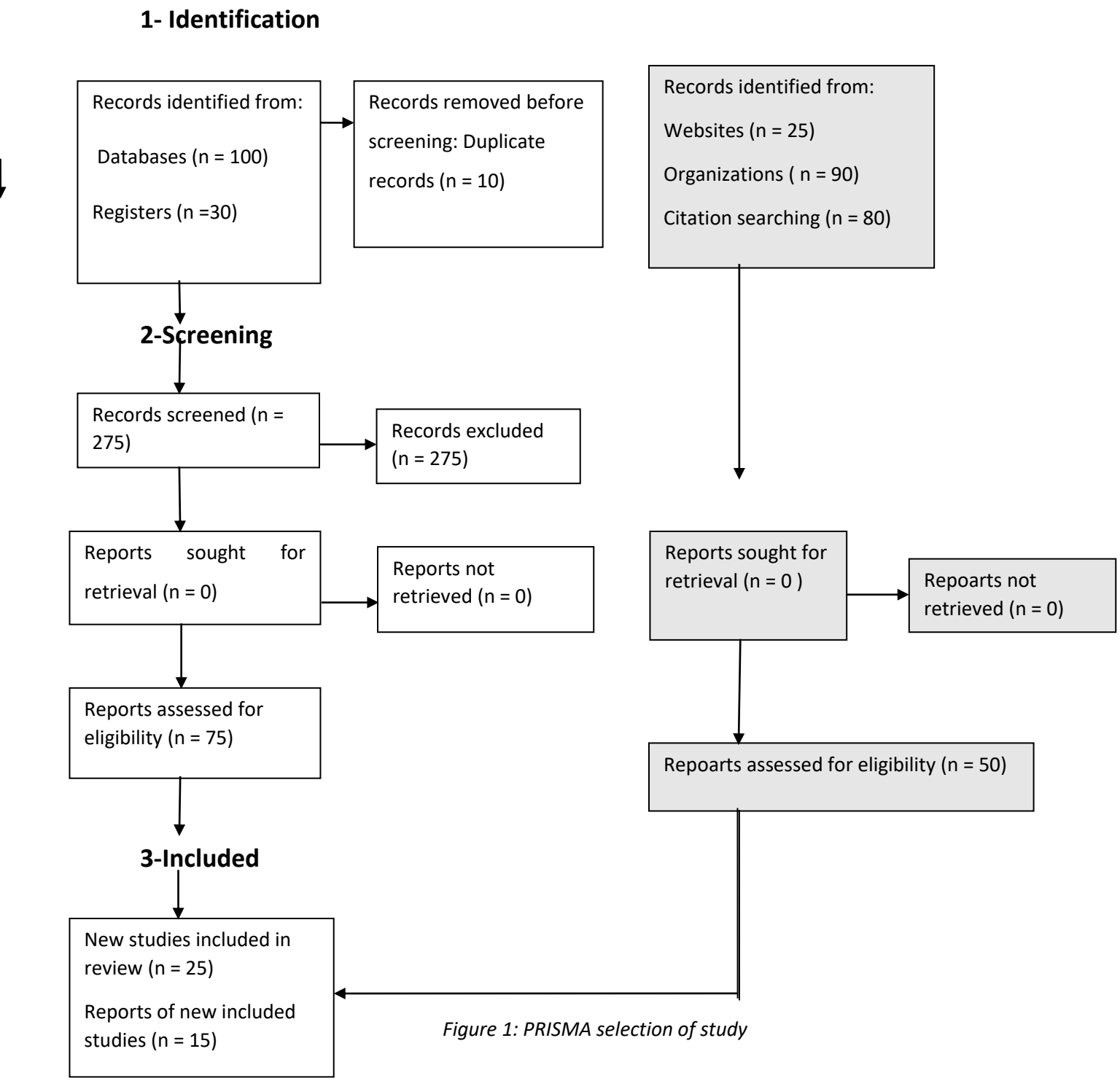

Figure 1: PRISMA selection of study

A systematic review or meta-analysis that adheres to PRISMA principles goes through three main phases, which are summarized in this table. During the Identification stage, extensive searches across several databases are used to find pertinent research, and the total number of records—after duplicates are eliminated—is obtained. In order to weed out irrelevant research, the Screening process entails evaluating titles, abstracts, and complete texts against predetermined inclusion and exclusion criteria. The Included phase, which concludes, enumerates the studies that satisfy all requirements and are incorporated into the final analysis, describing their features and the procedure used to collect the data. Transparency and rigor in the identification and selection of papers for the review are ensured by this systematic process.

The findings from the fifteen studies we included in this review are presented in the following table (Table 1).

		Research design	**Duration**	**Participants**	**Result**	**Reference**
1	Qureshi et al. (2023)	Comparative, Meta analysis,Qualitative analysis	Varied	M. A., Ashraf, E., Albaayit, S. F. A., Shafqat, W., Shareef, N., Sadaf, S., ... & Tasneem, S.	Common themes and patterns & Influence of rootstock on growth rate noted	Qureshi et al. (2023)
2	Sharma et al., (2015)	Scholarly	Complete	R. M., Dubey, A. K., & Awasthi, O. P	Impact of different rootstocks on physiological growth and development of grapefruit varieties in North India	Sharma et al., (2015)
3	Singh et al., (2022)	Genetic diversity, heritability, and	Not	G., Rattanpal, H. S., Gupta,	High heritability of rootstock diameter,	Singh et al., (2022)

		genetic advancement in mandarin genotypes in India	specified	M., & Sidhu, G. S.	scion diameter, fruit weight, seed	
4	Grotewold, E. (2006).	Citrus juice study	Not specified	N/A	Flavonoid content in citrus juices is rich and offers anti-inflammatory, antioxidant, anticancer properties research involves NMR spectroscopy, HPLC, and MS techniques to identify and quantify flavonoid components.	Grotewold, E. (2006).
5	Barbora et al., (2020)	Eco-geographic Survey and Genotype Collection	multiple growing seasons,	A. C., Deka, S., Kakoti, R. K., Dutta, J. P., Gogoi, A., & Saikia, J.	To enhance the agricultural and medicinal use.	Barbora et al., (2020)
6	Chandel, et al., (2022).	Extract pectin from non-traditional sources and fruit waste, as well as purifying it and characterizing it with FTIR, HPLC, and rheological testing.	Not Specified	Biswas, D., Roy, S., Vaidya, D., Verma, A., & Gupta, A.	To improve pectin output and quality from citrus genotypes, an integrated strategy integrating genetic, agronomic, and biochemical research is recommended,	Chandel, et al., (2022).

					along with the identification of chemical and enzymatic changes for industrial uses.	
7	Deb et al., (2022).	Citrus indica is studied by surveys in the field, morphological and biochemical characterisation, sensory evaluation, and interviews with locals.	Not specified.	Haorongbam, S.	Citrus indica's danger status is determined by identifying variables that impact it, offering conservation insights, and comprehending consumer preferences and agricultural problems	Deb, U., & Haorongbam, S. (2022).
8	Deng et al., (2020).	Interdisciplinary study combining historical inquiry, botanical discovery, and genetic biology using morphological studies, field surveys, molecular markers, and data	Not Specified	Yang, X., Yamamoto, M., & Biswas, M. K.	Enhanced understanding of citrus genetic diversity and domestication history, highlighting the need for comprehensive genetic research and conservation planning to protect	Deng et al., (2020).

		analysis to trace citrus domestication, cultivation, distribution, and genetic diversity in Asia.			and utilize valuable citrus germplasms.	
9	El Gengaihi et al., (2020).	Investigation of the medicinal potential of citrus wastes using molecular biology methods, chemical analysis (GC/MS), and biological tests, including DNA fingerprinting, volatile oil recovery, antibacterial activity assays, and cytotoxicity tests.	Not Specified	S. E., Mohammed, M. A., Aboubaker, D., Shoaib, R. M., Asker, M., Abdelhamid, S., & Hassan, E. M.	Identification of antimicrobial and cytotoxic properties of citrus waste oils, suggesting their potential use in pharmaceuticals.	El Gengaihi et al., (2020).
10	Benedetto et al., (2023).	Comprehensive review of the phytochemical composition and biological properties of Citrus medica	Not specified.	N., Carlucci, V., Faraone, I., Lela, L., Ponticelli, M., Russo, D., ... & Milella, L. (2023).	Identification of broad-spectrum antibacterial, antiviral, anti-inflammatory, antioxidant, neuroprotective,	Benedetto, N., Carlucci, V., Faraone, I., Lela, L., Ponticelli, M., Russo, D., ... &

		Linn. using PubMed and Scopus databases, including chemical analysis of volatile oils from citrus wastes and evaluation of their cytotoxic and antibacterial properties.			anticancer, and antidiabetic properties of Citrus medica, highlighting its extensive medicinal potential.	Milella, L. (2023).
11	Dongre, et al., (2023).	Systematic literature review on phytochemical composition and biological properties of Citrus sinensis, including assessment of antibacterial and cytotoxic properties of volatile oils from citrus wastes and genetic linkage analysis using PCR-based DNA fingerprinting.	Not specified	Doifode, C., Choudhary, S., & Sharma, N.	Identification of antioxidant, anti-inflammatory, antibacterial, antifungal, antidiabetic, and hypocholesterolemic properties of Citrus sinensis, suggesting potential applications in medicine and highlighting the medicinal benefits of citrus waste products.	Dongre, P., Doifode, C., Choudhary, S., & Sharma, N. (2023).

12	Lu et al., (2023).	Comprehensive analysis of the phytochemical composition and biological properties of Citrus sinensis, utilizing systematic literature review methods and comparative analysis across various citrus species, including molecular biology techniques.	Not Specified	X., Zhao, C., Shi, H., Liao, Y., Xu, F., Du, H., ... & Zheng, J.	Identification of nutrients and bioactive substances in Citrus sinensis contributing to its anti-inflammatory, antioxidant, anticancer, cardiovascular health, and immune-boosting properties, facilitating potential health applications.	Lu, X., Zhao, C., Shi, H., Liao, Y., Xu, F., Du, H., ... & Zheng, J. (2023).

13	Indriyani, et al., (2023).	Study on bioactive substances in citrus plant, Citrus aurantium, Citrus sinensis and citrus medica Linn. essential oils their properties. Utilization of citrus waste for medicinal chemicals, Extraction methods for citrus leaf essential oils, Chemical composition analysis using GC/MS and GC/FID	Not Specified	N., Anshori, J. A., Permadi, N., Nurjanah, S., & Julaeha, E.	Neuroprotective, antidiabetic, antioxidant, Antiviral, antibacterial, anti-inflammatory, antihyperglycemic, Aligns sustainability and circular economy concepts, production of important medicinal chemicals, 35 volatile chemicals identified and measured	Indriyani, N. N., Anshori, J. A., Permadi, N., Nurjanah, S., & Julaeha, E. (2023).

14	Lu et al., (2023).	Investigation of citrus peel bioactive flavonoids (hesperidin, naringin, quercetin) focusing on antiobesity and antidiabetic properties, utilizing phytochemical analysis, molecular biology, and computational methods.	Not Specified	K., & Yip, Y. M.	Identification of potent anti-inflammatory, antioxidant, and metabolic-regulating effects of citrus peel flavonoids, advocating for their pharmaceutical use and promoting sustainability through circular economy practices	Lu, K., & Yip, Y. M. (2023).
15.	Elhawary et al., (2024).	Comparative study on extraction methods (steam distillation, hydrodistillation, microwave-assisted distillation) of citrus leaf essential oils (Citrus aurantium),	Not Specified	E. A., Nilofar, N., Zengin, G., & Eldahshan, O. A.	Identification of 35 volatile chemicals in citrus leaf essential oils, highlighting their diverse bioactive properties and supporting their potential pharmaceutical applications, emphasizing sustainability and	Elhawary, E. A., Nilofar, N., Zengin, G., & Eldahshan, O. A. (2024).

		chemical analysis (GC/MS, GC/FID), and evaluation of bioactivities including antibacterial, antidiabetic, anti-inflammatory, and antioxidant properties.			circular economy practices.	

These fifteen studies were conducted from 2006-2024. certainly! Citrus plant research studies are summarized in the table, with an emphasis on several characteristics including phytochemical composition, biological qualities, genetic diversity, extraction techniques, and therapeutic uses. Every study has information on the duration, participants (if indicated), research strategy, findings, and reference citation.

The table compiles a range of research projects pertaining to citrus trees, including studies into their chemical composition, biological impacts, genetic variability, extraction techniques, and possible medicinal applications. Every study has a unique research design that describes the methods used, which might include extraction methods analysis, genetic diversity studies, comparative analysis, and systematic literature reviews. When available, duration information provides context for the timeframe or length of these research. Participants are listed, emphasizing the roles or researchers that are a part of each study. These research' findings and conclusions are summarized in their results. Important discoveries include the identification of bioactive substances in citrus species, such as terpenes, flavonoids, and essential oils, and the clarification of their antibacterial, antioxidant, and other medical benefits. While evaluations of extraction methods enhance the quantity and quality of bioactive extracts, genetic studies shed light on the variety and development of citrus. Together, these research enhance our understanding of citrus resources, highlight the importance of sustainability via the

implementation of circular economy techniques, and encourage their future uses in the medical field and other fields. Every item in the table has a thorough citation, including all necessary information such the authors, the year of publication, and the title. This makes it easier to reference and do more research in the area of citrus studies. When taken as a whole, these research highlight citrus trees' many functions, from their ecological value to their wide range of biomedical potentials, improving knowledge and application in a number of scientific fields.

Discussion

The tabular representation of various research endeavors highlights the comprehensive investigation of citrus trees, with an emphasis on chemical composition, biological functions, genetic variation, extraction methods, and possible therapeutic uses. All the studies used different approaches according to their own goals, and they all added important information about different facets of the biology and applications of citrus.

Research like those done by Benedetto et al. (2023) and Lu et al. (2023) evaluated Citrus medica Linn. and Citrus sinensis, respectively, in great detail with regard to their phytochemical makeup. They discovered a wide range of bioactive substances, including as terpenes, flavonoids, and essential oils, which are well-known for their strong antibacterial, anti-inflammatory, antioxidant, and even neuroprotective qualities. These results demonstrate citrus trees' potential as a natural source of medicinal compounds.

An integrative study by Deng et al. (2020) traced the genetic diversity and domestication history of citrus species throughout Asia. Their research improved our knowledge of citrus germplasm conservation and evolutionary history by utilizing morphological studies, field surveys, and genetic markers. The conservation of priceless citrus genetic resources and sustainable agriculture depend on these genetic insights.

Citrus leaf essential oils were extracted using a variety of techniques by Elhawary et al. (2024), with an emphasis on environmentally friendly procedures that follow the guidelines of the circular economy. Through GC/MS and GC/FID studies, their study found 35 volatile compounds, demonstrating the variety of bioactive characteristics of citrus oils. These results support the use of ecologically friendly extraction methods that optimize quality and production while reducing their negative effects on the environment.

Citrus essential oils have been shown to have wide-ranging therapeutic potential against a variety of ailments, including diabetes, inflammation, and microbial infections. This was the subject of research

conducted by Indriyani et al. in 2023. This emphasizes the bioactive chemicals found in citrus and their medicinal importance, opening the door for future therapeutic advances and medication development.

In the future, combining genetic research with sophisticated computer techniques and systematic reviews may help clarify the intricate relationships between citrus phytochemicals and their biological effects. Furthermore, research should concentrate on filling up information gaps about neglected citrus species and investigating their unrealized potential in medicinal and sustainable agricultural applications.

Conclusion

In summary, the compilation of research findings emphasizes the significant and diverse ways that citrus science has advanced both scientific knowledge and real-world applications. Numerous advantages of citrus trees have been shown by these research, including their nutritional worth, possible therapeutic uses, and environmental significance. It will take continual interdisciplinary work to maximize these benefits while advancing environmental sustainability and improving human health in the future. Research collaborations must to persist in investigating novel production techniques, environmentally-friendly management approaches, and the possible health advantages of citrus chemicals. In addition to boosting agricultural production, these initiatives also advance global initiatives for food security, biodiversity preservation, and enhanced public health.

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