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A comprehensive review of chemical composition and nutritional health benefits of coconut water

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Abstract

Coconut water, derived from young green coconuts, has gained recognition as an invigorating tropical beverage with diverse practical uses. It supports the growth of microorganisms and holds cultural significance in ceremonies and gift-giving. It can even be transformed into vinegar or wine. The global coconut water market has experienced rapid growth, led by the United States, followed closely by Europe and Brazil. In India, the market for packaged tender coconut water is promising, despite facing challenges like limited credit facilities and a shortage of tender coconuts. Coconut water offers numerous health benefits as a hydrating isotonic drink and a nutritious sports beverage. Its abundant minerals, vitamins, and phytohormones make it a refreshing and wholesome option for quenching thirst. Coconut water production requires meticulous cultivation and harvesting methods, utilizing thermal and non-thermal preservation techniques. The chemical and physical properties of coconut water, including its mineral composition and phytohormones, contribute to its therapeutic effects and health-enhancing properties. Scientific research supports its role in hydration, reducing inflammation, and providing antioxidative benefits, positioning it as a promising functional food. Consumer perception of coconut water is overwhelmingly positive, driven by a growing demand from health-conscious individuals. Despite the expectation of significant market expansion, the industry must address credit availability and coconut supply challenges. Overall, coconut water shows remarkable growth potential and offers a rejuvenating and healthful alternative in the ever-changing beverage industry.

Keywords: Coconut water; health, benefits, hydration, function food

1. Introduction

Coconut water, a sweet and crystal-clear liquid, is a naturally occurring liquid found within the cavity or endosperm of a young and green coconut. Coconut water, beyond its reputation as a refreshing tropical drink, holds various traditional and functional uses (Ediriweera, 2003) ^[1]. It serves as a medium for microorganisms' growth (Osazuwa, *et al.*, 1989) ^[2] and lends itself well to gift-giving and ceremonies (Rethinam, *et al.*, 2001) ^[3]. Moreover, coconut water can be transformed into vinegar (Sanchez, *et al.*, 1985) ^[4] or even wine in an innovative culinary spine (Augustine, *et al.*, 2007) ^[5]. Coconut water is a dual-purpose drink, acting as both an isotonic beverage (Rethinam, *et al.*, 2001) ^[3] and a nutritional sports drink. Coconut tree has a wide distribution spanning across Southeast Asia, Indonesia, India, Australia, the Pacific Islands, South America, Africa, the Caribbean, as well as the southernmost parts of North America. Consumed primarily in tropical or coastal regions, coconut and its water are staples of the local diet (Tuyekar, *et al.*, 2021) ^[6].

The uncertain centre of origin of the Coconut tree has long been a puzzling mystery. It has been noted that there are three perspectives on the origin of the subject at hand. The first suggests its American provenance, while the second links it to the Indo-Malayan region. The third viewpoint, however, suggests that its roots may lie in Indo-African origins (Mahabale, *et al.*, 1976) ^[8]. However, Organic historic scripts propose that coconut trees held a crucial part in various cultural and customary significances, especially in Hinduism and Buddhism (Nayar, 2017) ^[7]. During the early Polynesian exploration of the South Pacific, the coconut was introduced to the Hawaiian Islands and is still regarded as such (Ahuja, *et al.*, 2014) ^[9]. Archaeological, historical, written records, and geographical resources have narrowed down the origin of the coconut tree to various areas, including the Indian archipelago, northern Indian Ocean, southeast Asia, Philippines, New Guinea, and the west Pacific (Nayar, 2017) ^[7]. Coconut water is a beverage with excellent thirst-quenching properties and has a caloric value of 17.4 per 100 grams (DebMandal, *et al.*, 2011) ^[10]. Coconut water is 94% water containing sugars like aldohexose, fructose, and disaccharide making up around 5%.

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The presence of proteins and lipids is minimal, accounting for just 0.02% and 0.01%, respectively (Tuyekar, *et al.*, 2021) ^[6]. Tender coconut water comprises a plethora of minerals including potassium, sodium, calcium, phosphorous, iron, copper, and magnesium among others (Anurag and Rajmohan, 2007) ^[11]. Utilizing Tender Coconut water (TCW) can prevent oxidative stress, inhibit lipid peroxidation, improve lipid profile, regulate blood pressure, intensify cardio-protective activity, and provide anti-inflammatory, anti-diarrheal, and anti-thrombotic effects. Experimental studies on both humans and animals have shown that TCW can play a vital role in mitigating the risk of diabetes and boosting haemoglobin levels (Sunil L., *et al.*, 2020) ^[12]. Therefore, Tender Coconut water is an invigorating and healthful alternative for hydration and is a rich source of plethora of minerals that offer various health benefits.

2. Production and Processing of Coconut water

India is one of the world's top four coconut-producing countries with over 2,173 thousand hectares of land allocated to coconut cultivation. The nation yields a remarkable 20,309 million nuts each year, a high productivity rate of 9,346 nuts per hectare (Department of horticulture, 2020) ^[13]. The dwarf coconut tree is primarily employed for the manufacture of coconut water (Lemos, 2023) ^[14]. A ripe coconut matures in six to nine months, becoming a soft coconut that is ideal for coconut water extraction. The water obtained from it can be ingested directly or processed into an assortment of beverages (Zhang *et al.*, 2020) ^[15].

The coconut tree is capable of thriving in diverse soil and climatic conditions. This tropical plant necessitates an environment with a temperature of around 27 degrees Celsius and a humidity level of over 60% for the optimal growth and development. These plants can be grown at elevations up to 600 meters above mean sea level. In order to achieve the growth of tender coconuts for its water, it is crucial that one takes into consideration the agro climatic requirements, carefully selects suitable coconut cultivars such as tall, dwarf and hybrid plants, chooses the right site for planting, and uses high quality planting materials. Additionally, one must take strict measures to control pests and diseases that may affect the crop's growth. All these factors collectively play a pivotal role in the triumphant cultivation of coconuts (Ministry of Agriculture & Farmers' Welfare).

Coconut palms necessitate meticulous harvesting conditions and precise assessment of their optimal maturation stage (Rao *et al.*, 2008) ^[17]. The gathering of coconuts transpires at varying intervals across the calendar year. Bunches of coconuts are consistently engendered in diligently cultivated and highly productive gardens, warranting a monthly harvesting endeavour (Ministry of Agriculture & Farmers' Welfare). The attainment of average fruit maturity in coconuts occurs within the timeframe of 11 to 12 months. Categorization of the fruit hinges upon its chemical composition, whereby it may be deemed as either immature or tender (between six to eight months), mature (between nine to eleven months), or excessively mature (twelve months or beyond). Notably, young tender coconuts exhibit the highest quantum of coconut water volume (Walker *et al.*, 2020) ^[19]. The most optimal strategy for preserving coconut water within its inherent receptacle remains the utilization of tender, juvenile coconuts; however, it is imperative to note that these nuts are susceptible to spoilage and must not exceed the room

temperature storage duration of six days (Gatchalian *et al.*, 1993) ^[18].

In the realm of coconut water preservation derived from youthful, delicate coconuts, both thermal and non-thermal processing methodologies are employed. While thermal processing approaches, encompassing evaporation, pasteurization, and sterilization, have been conventionally employed, they bear the drawback of compromising the organoleptic attributes and intrinsic nature of the coconut water. Consequently, non-thermal processing techniques emerge as a viable alternative, facilitating the assurance of microbiological and chemical integrity throughout the processing and storage phases. Furthermore, these non-thermal techniques not only aid in the preservation of coconut water but also serve to uphold its shelf life (v. Prithviraj *et al.*, 2021) ^[20].

The scholarly investigation conducted by Prades *et al.* (2012) ^[21] centered its focus on the meticulous examination of the quality attributes and longevity pertaining to processed coconut water. Conventional thermal modalities, including pasteurization, sterilization, and microfiltration, proved inadequate in conferring a state of shelf stability upon coconut water devoid of supplementary additives. Nevertheless, the fortification of the aforementioned techniques with compounds such as nisin, ascorbic acid, citric acid, and sodium metabisulphite yielded promising outcomes, evincing improved preservation and a noteworthy extension in the shelf life by a duration of approximately 2-3 months when subjected to ambient temperature or refrigeration. Notably, the application of sterilization techniques furnished an even more protracted period of viability, boasting an impressive shelf life of up to 10 months at ambient temperature and 12 months when stored at a controlled temperature of 4°C. Furthermore, the deployment of microfiltration methodologies facilitated enhanced lucidity, accompanied by the alleviation of turbidity and a reduction in protein content. Regrettably, the persistence of a pink discoloration was encountered in micro filtered coconut water derived from Dwarf varieties, despite the aforementioned enhancements. Ultra filtration, on the other hand, showcased its prowess in effectively retaining essential enzymes and vital minerals, thereby serving as a promising avenue for preserving the commendable quality standards espoused by young coconut water beverages. It is pertinent to underscore the conspicuous variability that characterizes commercially available coconut waters, thereby highlighting the indispensability of meticulous adherence to rigorous hygienic practices, robust packaging methodologies, meticulous storage protocols, and stringent quality control measures. Collectively, these studies eloquently emphasize the pressing need for the continual refinement of processing techniques and the implementation of astute management practices in order to ensure unwavering safety and unblemished quality for processed coconut water.

3. Recent Advancements in the production and processing of Coconut water

Recent progress in the processing and conservation of tender coconut water encompasses both thermal and non-thermal methodologies. Thermal approaches, such as traditional heating, filtration, and ultraviolet treatment with the addition of chemical additives, are commonly employed. Nevertheless, these methods may engender adverse repercussions on the product's quality and the acceptance of consumers.

Conversely, non-thermal techniques offer notable advantages, including diminished product loss, minimal deterioration of quality, and reduced processing time. Among these methods are ultrasound processing, ohmic heating, microwave processing, cold plasma processing, and high-pressure carbon dioxide treatment. Ultrasound processing has been observed to effectively stabilize the enzymatic and microbial activity present in coconut water. Cold plasma processing, which entails utilizing plasma-activated water, exhibits promising potential for decontaminating fresh produce and sterilizing processing equipment. Various filtration methodologies, such as ultrafiltration, microfiltration, reverse osmosis, and nanofiltration, have been implemented to eradicate contaminants and enhance the quality of coconut water. High-pressure carbon dioxide processing has been shown to efficaciously neutralize microorganisms and prolong the shelf life of coconut water. The utilization of high-pressure techniques, involving subjecting coconut water to pressures ranging from 400 to 600 MPa, has achieved successful reduction of harmful bacteria levels without compromising the water's composition. On the whole, a synergistic employment of diverse processing methods, commonly known as hurdle technology, has demonstrated effectiveness in extending the shelf life of coconut water while preserving its inherent quality attributes. Nonetheless, further research is imperative to establish standardized protocols and optimize these methods for industrial-scale processing.

4. Chemical and Physical Characteristics of Coconut Water

4.1. Analysis of Chemical Composition

Coconut water harbors phytohormones, namely auxins, cytokinins, gibberlins, and Abscisic acid (ABA), which function as plant growth regulators. Additionally, it is rich in a plethora of minerals encompassing potassium, calcium, magnesium, iron, sodium, phosphorus, zinc, manganese, copper, sulphur, aluminium, boron, selenium, and chlorine. Within these minerals, potassium predominates, followed by sodium as the subsequent prominent element. Coconut water encompasses an array of B-vitamins, specifically thiamine (B1), riboflavin (B2), niacin (B3), pantothenic acid (B5), pyridoxine (B6), biotin (B7), and folate (B9) (Jean *et al.*, 2009) [22].

Coconut water is endowed with the primary auxin, Indole-3-acetic acid (IAA), which assumes a pivotal role in regulating diverse physiological processes in plants. (Ma *et al.*, 2008) [23] and (Wu and Hu, 2009) [24]. Indole-3-acetic acid (IAA), belonging to the auxin class of plant hormones, assumes prominence as the prevailing phytohormone, overseeing a multitude of facets pertaining to plant growth and development (Fu *et al.*, 2015) [25]. Auxin orchestrates a multitude of pivotal processes in plants, encompassing cell division, differentiation, fruit development, root induction from cuttings, and leaf shedding, while concurrently facilitating stem elongation, impeding lateral bud proliferation, and upholding apical dominance via the stimulation of cell elongation within the apical meristem (Jamil *et al.*, 2021) [26].

Cytokinins, purportedly, emerge as a captivating phytohormone that manifests its presence within coconut water, entailing considerable intrigue and scientific interest. Earlier research has elucidated notable health advantages attributed to significant anti-aging, anti-carcinogenic, and

anti-thrombotic properties (Mohd *et al.*, 2015) [27]. Cytokinins, in their multifaceted capacity, undertake a myriad of pivotal functions, encompassing cellular mitosis, chlorophyll biosynthesis, induction of tissue specialization, initiation of seed germination, generation of buds, mitigation of apical dominance, facilitation of leaf expansion, and facilitation of reproductive maturation (Ge *et al.*, 2004) [28]. Abscisic acid (ABA), as another phytohormone found in coconut water, governs stress-related reactions and regulates a plethora of facets pertaining to plant growth and development (Kepka *et al.*, 2011) [29]. Gibberlins, being the fourth growth regulator present in coconut water, meticulously govern the intricate mechanism underlying plant growth and development, explicitly demonstrating their influence on pivotal facets such as seed germination, elongation of epidermal cells, amplification of foliage and advancement of floral maturation (Jean *et al.*, 2009) [22]. Consequently, the discernment of these four plant growth regulators within coconut water not only proves advantageous to plant scientists utilizing it as a growth regulator supplement in tissue culture, but also furnishes substantial insights into the biochemical efficacy of coconut water in fostering plant growth and development (Tan *et al.*, 2015).

Table 1: Mineral Composition of coconut water (Santoso *et al.*, 1995) [30]

Vitamins	Tender coconut water	Mature coconut water
Calcium (% DM)	0.47	0.57
Magnesium	0.11	0.11
Potassium	3.50	4.64
Sodium	0.03	0.29
Phosphorus	0.08	0.23
Sulphur	0.01	0.07
Manganese (ppm)	20.3	14.4
Iron	4.06	2.94
Zinc	11.3	3.51
Copper	0.96	5.32
Boron	12.8	14.3

Table 2: Vitamin content of Coconut water (Santoso *et al.*, 1995) [30]

Vitamins	Tender Coconut water	Mature Coconut water
Vitamin B ₁ (mg/100g DM)	Trace	0.01
Vitamin B ₂	0.01	0.01
Vitamin B ₃	ND	ND

4.2. Physical properties of Coconut water

The coconut encapsulates an endocarp, characterized by its inflexible shell, enshrouded by a fibrous outer layer commonly recognized as the mesocarp or coconut husk. Situated within the endocarp lies the kernel, alternatively acknowledged as the endosperm, comprising the desiccated pulp of the coconut fruit. Nestled within the kernel's cavity, one finds the coveted elixir known as coconut water (Reddy and Lakshmi, 2014) [31]. Coconut water, a limpid fluid exhibiting a cloudy aspect, presents itself as a viable substitute to conventional water, offering an invigorating elixir that satiates thirst and is conveniently accessible across the nation. The distinctively delectable and nutty taste of coconut water can be attributed to the presence of deltalactone, as well as an amalgamation of polyphenol oxidase, peroxidase, and assorted enzymes (L., *et al.*, 2020) [12].

Upon careful examination, it was determined that the coconut water exhibited a total alkali content measuring 13.8 milliequivalents per liter (mEq/L) (Patel *et al.*, 2018) [32]. Moreover, the average specific heat value for the coconut water corresponded to 4.06 kilojoules per kilogram per degree Celsius (kJ/kg/C). Notably, the density of coconut water showcased a range spanning from 1.54 to 0.36 times 10 to the power of negative 3 Pascal-seconds (Pa*s), with the lower limit observed at 5 degrees Celsius and the upper limit at 80 degrees Celsius (Fontan *et al.*, 2008) [33]. Additionally, the turbidity of the coconut water exhibited an upward trend in relation to the fruit's maturity, whereas the pH demonstrated an upward shift accompanied by a corresponding decrease in acidity. The soluble solids, quantified by their °Brix value which indicates the total sugar content, displayed an ascending pattern until 12 months of maturity, after which a decline was observed. From approximately 7 months onwards, a general reduction in °Brix values was noted (Burns *et al.*, 2020).

5. Health Benefits and Therapeutic Properties of Coconut Water

5.1. Revitalizing Hydration

Coconut water exudes an innate prowess to harmonize and perpetuate the delicate dance of electrolytic equilibrium within the intricate tapestry of the human body, akin to a conductor orchestrating a symphony of balance. The unrivaled characteristics and exceptional properties of the coconut water stands as the ultimate elixir to replenish and invigorate the body after demanding physical exertion, akin to a wellspring of revitalization (Reddy P, 2003) [34]. Coconut water has garnered recent fervent scrutiny as an innate substitute for industrially synthesized sports drinks, manifesting promising initial indications of its efficacy in upholding and sustaining optimal levels of hydration (Kalman *et al.*, 2012) [35]. The antecedent intake of coconut water (CW) yields a notable enhancement in exercise capacity under hot conditions, endowing a heightened ability to endure physical exertion. Moreover, Coconut water surpasses plain water and flavored beverages in terms of fluid retention, establishing itself as an unparalleled option. Notably, Coconut water gracefully avoids any gastrointestinal disturbances, thereby solidifying its reputation as a consummate companion for optimal performance and recovery in arduous athletic endeavours (Laitano *et al.*, 2014) [36]. The integration of sodium chloride into the constitution of coconut water is advocated as a strategic measure to rectify the dearth of sodium and chloride ions, thereby restoring equilibrium and addressing the deficiency. As a result, coconut water emerges as a promising and formidable contender for the oral rehydration therapy of individuals grappling with acute gastroenteritis under circumstances where conventional fluid provisions are unattainable (Kuberski *et al.*, 1979) [37]. Moreover, Coconut water has undergone comprehensive evaluation as a plausible therapeutic agent for fluid restoration during instances of diarrheal affliction. Its efficacy in ameliorating dehydration, replenishing electrolytes, and optimizing hydration status has been subject to meticulous scrutiny.

5.2. Anti-inflammatory and Anti-oxidant properties

Embarking upon a journey towards elucidating the remarkable properties of coconut water, it becomes evident

that its consumption possesses the inherent ability to fortify the body's antioxidant systems. Acting as a shield against the pernicious impact of free radicals and effectively mitigating the likelihood of developing cardiovascular disorders, coconut water emerges as a precious gem gleaming amidst the vast expanse of options in the realm of health and medicine (Agbafor *et al.*, 2015) [38]. Coconut water unveils an extraordinary profusion of formidable antioxidants, showcasing an impressive arsenal of protective compounds that combat the detrimental effects of oxidative stress. Manifesting heightened concentrations of fructose and glucose, the composition of coconut water stands distinguished. It is particularly noteworthy that coconut sap exudes augmented levels of vital vitamins, encompassing the likes of C, B1, B3, B4, and B10. In consequence, coconut water emerges as an exalted and auspicious reservoir, harboring immense potential for engendering a healthier alternative to the customary saccharine counterpart (Asghar *et al.*, 2019) [39].

Coconut water encompasses a diverse range of health-related properties, including antihyperlipidemic (Sandhya and Rajmohan 2008) [40], antiulcerogenic, and cardioprotective effects (Anurag and Rajmohan, 2008) [11], underscoring its multifaceted significance in promoting overall well-being. Both nascent and mature coconut water exemplify remarkable anti-inflammatory activity, evincing substantial effectiveness in ameliorating inflammatory processes (Rao and Najam, 2016) [43]. The consumption of coconut water among individuals devoid of stone-forming tendencies engenders a discernible amplification in the excretion of urinary potassium, chloride, and citrate, while concurrently preserving the delicate homeostasis of urine pH (Patel *et al.*, 2018) [32]. This intriguing observation underscores the intricate interplay between coconut water and the renal system, highlighting its potential as a valuable adjunct for the preservation of urological well-being. The youthful elixir of coconut water outshone not only its mature counterpart but also the conventional pharmaceutical ibuprofen, asserting its unparalleled supremacy in terms of effectiveness and efficacy (Asghar *et al.*, 2019) [39]. It stood as a beacon of unparalleled success, casting a shadow over its counterparts in the pursuit of optimal outcomes.

6. Use of Coconut water as function food

The surging demand and widespread acceptance of coconut water as a functional food can be attributed to its burgeoning reputation for hosting a myriad of health benefits. Renowned for its copious reservoir of antioxidants, vitamins, and electrolytes, among other constituents, coconut water surpasses the nutritional value of milk, orange juice, and processed baby milk, as established by various scientific research papers (Chinasa, 2018). Within the realms of scientific research, coconut water has garnered profound acclaim for its abundant reservoirs of kitenin, an extraordinary bioactive compound celebrated for its unrivaled prowess in defying the aging process. Derived exquisitely from the very heart of coconuts, this organic elixir has engendered a crescendo of fascination among scholars, owing to its auspicious potential in heralding longevity and rejuvenation (Ge *et al.*, 2005) [43].

The burgeoning global phenomenon of integrating lactic acid bacteria (LAB) into the culinary realm, particularly in non-dairy concoctions infused with probiotic strains, has been

surging with remarkable impetus. Nevertheless, intricate quandaries emerge with regards to the meticulous techniques of processing and storing, indispensable for safeguarding the vitality of these symbiotic microorganisms. Although fermented coconut water stands as an inherently functional elixir, revered for its multifarious health advantages, the realm of fermented beverages derived from this aqueous nectar remains stunted in terms of technological advancement. In an earnest endeavor to bridge this lacuna, the study embarked upon the development of an avant-garde fermented libation, meticulously crafted around the nucleus of coconut water as its *pièce de résistance*. Manifesting a harmonious symbiosis between the functional merits bestowed by the beverage and the innate hydrating virtues intrinsically possessed by coconut water, it emerges as an irresistible epicurean choice for discerning adherents of vegetarianism and those grappling with lactose intolerance (Prado *et al.*, 2015) ^[44].

Coconut, an object of profound scrutiny, has undergone comprehensive examination owing to its advantageous attributes, chiefly its exalted abundance of phenolic compounds and flavonoids. These remarkable constituents, endowed with their potent antioxidant properties, serve as guardians against the ravages of oxidative stress within cellular realms. Notably, the elixir of coconut, known as coconut water, has emerged as an exemplar of efficacious radical scavenging and redox potential, all attributable to its resolute concentration of phenols. This commendable capacity of coconut water extends its protective mantle even unto the perilous domain of lipid peroxidation, wherein it effectively curtails the genesis of noxious substances. These enlightening revelations proffer a tantalizing prospect: the therapeutic potential of coconut water stands poised to alleviate maladies borne from the crucible of oxidative stress, whilst concurrently bestowing the mantle of cognitive augmentation upon those who partake in its nectar (Praia *et al.*, 2021) ^[45].

7. Scientific Findings on the health benefits of Coconut water

The consumption of tender coconut water is associated with a multitude of advantageous health effects. In an investigative endeavor, researchers undertook a study to ascertain the impact of this invigorating liquid on gold miner laborers who endure constant exposure to the perils of mercury. These industrious individuals were subjected to a predetermined quantity of coconut water within a stipulated timeframe. The arduous exposure to excessive levels of mercury induced heightened oxidative stress and impeded the proper functioning of antioxidant enzymes. Nevertheless, the findings subsequent to the consumption of tender coconut water by these workers revealed a notable surge in antioxidants, facilitating the restoration of physical well-being and mitigating the adverse consequences of mercury (Zulaikhah and Suwondo, 2015) ^[46].

The empirical evidence derived from research (Sandhya and Rajmohan, 2006) ^[47] demonstrates that the consumption of tender and mature coconut water has a profound hypocholesterolemic tendency in rats subjected to a high-cholesterol diet. Coconut water also shows potential in lipid concentrations. The study revealed significant lipid profile changes in rats fed a diet rich in fat and cholesterol. This diet led to increased levels of serum total cholesterol, VLDL + LDL cholesterol, and triglycerides, along with decreased

HDL cholesterol and an elevated atherogenic index. However, supplementation with coconut water or lovastatin resulted in substantial reductions in total cholesterol, VLDL + LDL cholesterol, triglycerides, and the atherogenic index, while significantly increasing HDL cholesterol, similar to the control group. Interestingly, the tender coconut water group exhibited higher concentrations of total cholesterol and LDL + VLDL cholesterol compared to the normal group. Furthermore, rats on the fat-cholesterol diet displayed heightened total cholesterol and triglycerides in crucial organs such as the liver, heart, kidney, and aorta compared to the normal group. Nonetheless, the administration of both tender and mature coconut water, as well as lovastatin, significantly lowered tissue cholesterol and triglyceride levels, albeit remaining higher than in the control rats. Notably, the lipid-lowering effect was more pronounced in the coconut water-supplemented rats compared to those treated with lovastatin (Sandhya and Rajmohan, 2008) ^[40].

Coconut water exhibits potent anti-inflammatory properties, as demonstrated by a comprehensive investigation evaluating the anti-inflammatory effects of juvenile and mature coconut water vis-à-vis ibuprofen, employing a rat paw edema model. The inflammatory response, incited by acetic acid, triggered the sequential release of inflammatory mediators during two distinct phases. Remarkably, both juvenile and mature coconut water exhibited profound anti-inflammatory effects, attributed to their intricate flavonoid composition, robust antioxidative potential, and remarkable antihistaminic attributes. The juvenile coconut water showcased a heightened influence on histamine, serotonin, and prostaglandin synthesis, plausibly attributable to its elevated salicylic acid content. Conversely, mature coconut water predominantly targeted histamine and serotonin. These compelling findings substantiate the prospective application of both coconut water variants as potent anti-inflammatory agents, with the juvenile counterpart displaying superior efficacy. However, it is imperative to conduct further investigation to unravel the precise molecular mechanisms governing their therapeutic efficacy (Rao and Najam, 2016) ^[43]. Coconut water, renowned for its cardiac fortitude, was investigated in a study on doxorubicin-induced cardiomyopathy in rats. Elevated LDH, AST, and ALT levels indicated heart tissue damage caused by doxorubicin. The drug's production of free radicals and subsequent oxidative stress were implicated in cardiomyopathy. However, treatment with coconut water significantly reduced LDH, AST, and ALT levels. The presence of cytokinins in coconut water likely contributed to this effect. Furthermore, doxorubicin-induced cardiomyopathy depleted antioxidant vitamins C and E, but coconut water replenished their levels. These antioxidants play a crucial role in mitigating the harmful effects of free radicals. In summary, coconut water shows promise in protecting against doxorubicin-induced cardiomyopathy by counteracting oxidative damage (Kennedy *et al.*, 2013) ^[48].

8. Consumer Perception and Market Trends towards Coconut water

As per the Coconut Development Board's report, coconut water garners considerable esteem from consumers due to its perceived nutritional and health merits, positioning it as a formidable contender to carbonated libations. Despite its relatively elevated price point compared to other market

offerings, packed tender coconut water is deemed a justifiable expenditure by discerning consumers. The singular taste and inherent qualities of coconut water elicit genuine admiration from its imbibers. While some individuals regard coconut water as a salubrious substitute for its fresh counterpart, others express concerns regarding potential nutrient degradation during the processing stages. Furthermore, consumer comportment towards coconut water evinces a proclivity for sampling an array of brands, with the brand Cocojol reigning supreme as the favored choice. The consumption of coconut water surges notably during the sweltering summer season, owing to its unrivaled rejuvenating and parch-quenching properties. E-commerce platforms such as Amazon, Big Basket, company websites, and India Mart emerge as the preferred conduits for procuring coconut water. The purchasing modality is influenced by an amalgamation of factors, including temporal considerations, product availability, consumer awareness, purchasing convenience, promotional incentives, haptic encounters, and price dynamics. On the whole, consumers manifest a sanguine outlook towards coconut water, primarily driven by its salutary attributes and unparalleled convenience, thus fortifying their predilection for this invigorating elixir.

The prevailing market trends surrounding the consumption of coconut water depict a resolute upsurge in its desirability. It has emerged as an esteemed elixir, particularly favored by health-conscious individuals seeking a virtuous and salubrious alternative to carbonated libations. The global expanse of the coconut water industry has experienced an extraordinary surge, characterized by an exponential expansion, doubling its scale year after year since the inception of 2005. Notably, within the confines of the United States alone, the domain of coconut water already commands a substantial market value of a staggering Rs. 26,800 million, with projections of transcending into an impressive billion-dollar sector by the advent of 2014. The lion's share of the American market is currently dominated by Vita Coco, an unrivaled presence, while the paramount position across European territories is firmly established by the esteemed brand, Green Coco. Unquestionably, Brazil assumes the mantle of the largest consumer of coconut water, illustrating an insatiable appetite for this nourishing elixir. In the context of India, the packaged tender coconut water market is still in its embryonic stages, albeit showcasing palpable growth prospects, owing to an exponential surge in health consciousness and a discernible predilection for natural and invigorating beverages. The market itself manifests as a niche and fragmented entity, populated by a select cohort of players scattered across diverse regional enclaves. Prime urban centers such as Delhi, Bangalore, Ahmedabad, and Mumbai constitute the veritable bastions of market fortitude within India. Stakeholders within the industry harbor sanguine expectations of substantial market expansion, attributable to the enticements offered by packaged coconut water, including its enhanced longevity on the shelf and its heightened convenience for on-the-go consumption. Nevertheless, industry participants contend with a myriad of challenges, encompassing the dearth of accessible credit facilities and the chronic scarcity of tender coconuts, which pose impediments to sustained growth. All in all, the overarching market trends cast a positive light upon the prospects of coconut water, underscored by an unflinching surge in demand and an auspicious trajectory for future market expansion.

9. Conclusion

In conclusion, coconut water has emerged as an incredibly versatile tropical elixir with an abundance of practical applications. Its unique ability to foster the growth of microorganisms, coupled with its profound cultural significance in ceremonial and gifting traditions, underscore its wide-ranging uses. Moreover, the transformative nature of coconut water is exemplified by its conversion into vinegar or wine, which adds an enticing dimension to its already captivating appeal. The global coconut water market has experienced a rapid surge, with the United States, Europe, and Brazil spearheading this growth trajectory. Despite encountering obstacles such as restricted access to credit facilities and a scarcity of tender coconuts, the Indian market for packaged tender coconut water displays promising prospects.

From a holistic standpoint, coconut water boasts a plethora of health benefits. It serves as an invigorating isotonic beverage, replenishing the body's hydration needs while providing a nutritional boost. The ample reservoir of vital minerals, vitamins, and phytohormones within coconut water positions it as an exceptional choice for satiating thirst in a refreshing and nourishing manner. The production of coconut water necessitates meticulous cultivation and harvesting methods. Both thermal and non-thermal techniques are employed to preserve the integrity of this exquisite elixir, safeguarding its chemical and physical attributes. By implementing thermal preservation techniques such as pasteurization and sterilization, harmful microorganisms are effectively eliminated while preserving the valuable nutrients present in coconut water. Additionally, non-thermal methods like ultrafiltration and high-pressure processing offer alternative means of preservation, minimizing nutrient loss and extending the shelf life of this precious beverage. These conscientious practices play a pivotal role in ensuring the freshness and superior quality of coconut water, ultimately enhancing consumer satisfaction.

For researchers with an inquisitive disposition towards coconut water, this intricate elixir presents a captivating and multifaceted subject for further exploration. The myriad practical applications, dynamic market dynamics, profound health benefits, and intricate production processes of coconut water collectively form a rich tapestry that beckons scholarly investigation. Delving into the cultural significance and traditional uses of coconut water can shed illuminating insights on its historical context and contribute to the preservation of cultural heritage. Additionally, venturing into uncharted territories by investigating the untapped potential of coconut water in diverse industries such as gastronomy, cosmetics, and pharmaceuticals can unlock novel possibilities and catalyze innovative breakthroughs. Furthermore, delving into the impact of various preservation techniques on the chemical composition and sensory attributes of coconut water can provide invaluable knowledge for both manufacturers and researchers, pushing the boundaries of scientific understanding.

In conclusion, coconut water, with its remarkable versatility and multifaceted nature, has transcended conventional boundaries to establish itself as a global sensation. The exponential growth of the global coconut water market, driven by key regions like the United States, Europe, and Brazil, is a testament to the escalating demand for natural and health-enhancing beverages. Despite encountering challenges,

the Indian market for packaged tender coconut water showcases promising prospects and represents an untapped reservoir of opportunity within the country. With its abundant health benefits, coconut water serves as an invigorating and nourishing choice for hydration. Meticulous cultivation, harvesting techniques, and preservation methods ensure the preservation of its chemical and physical properties, ultimately augmenting consumer satisfaction. For researchers, the enigmatic nature of coconut water offers a captivating realm for scholarly exploration, encompassing practical applications, market dynamics, health benefits, and intricate production processes. By delving into this multifaceted domain, researchers can contribute to the comprehension and appreciation of coconut water's extraordinary qualities and its profound place in our diverse

10. References

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