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Eco-physiological response of secondary metabolites of teas: Review of quality attributes of herbal tea

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Herbal tea is a rich source of secondary metabolites which are reputed to have medicinal and nutritional efficacy. These secondary metabolites are influenced by the abiotic and biotic stresses that improve the production of herbal teas in terms of biomass production, accumulation and partitioning of assimilates of compounds. In this study, various examples of herbal teas have been shown to respond differently to secondary metabolites affected by environmental factors. Thus, the meta-analysis of this study confirms that different herbal teas' response to environmental factors depends on the type of species, cultivar, and the degree of shade that the plant is exposed. It is also evident that the metabolic processes are also known to optimize the production of secondary metabolites which can thus be achieved by manipulating agronomic practices on herbal teas. The different phenolic compound in herbal teas possesses the antioxidant, antimicrobial, antiatherosclerosis, anti-inflammatory, antimutagenic, antitumor, antidiabetic and antiviral activities that are important in managing chronic diseases associated with lifestyle. It can be precluded that more studies should be conducted to establish interactive responses of biotic and abiotic environmental factors on quality attributes of herbal teas.

KEYWORDS

herbal tea, medicinal properties, polyphenolic compounds, health benefits, environmental factors

Introduction

In its 2014–2023 strategy, the World Health Organization (WHO) aims to promote utilization of traditional medicines, including herbal medicine, with the goal of keeping populations healthy by providing access to efficient and reasonably priced alternatives to medicine and by offering healthcare options that are consistent with people's cultural practices (World Health Organization, 2013). Therefore, there is a need to develop new herbal teas from the underutilized herbal plants if we are to achieve WHO strategy. The consumption of herbal teas is gaining attraction in recent years because most of them are rich in natural bioactive components such as alkaloids, carotenoids, coumarins, flavonoids, polyacetylenes, and terpenoids (Chandrasekara and Shahidi, 2018).

Herbal tea is an aqueous infusion of different plant materials in hot or cold water to extract the phytochemical constituents (Poswal et al., 2019). It is produced from different plant parts, such as flowers, roots, barks, and seeds, compared to the traditional leaves of black tea. Herbal teas exist in different taste, color, and smell depending on the blend's preparation of other plants (Phelan and Rees, 2003; Malongane et al., 2020) and are referred to as "tisanes" (Sehgal, 2022). Its brewing process only takes 5–10 min, and it is served immediately (Omogbai and Ikenebomeh, 2013, Sharpe et al., 2016). Herbal tea has low calories and can be used as a relaxing drink.

A high intake of herbal tea as a beverage reduces the risk of chronic diseases due to antioxidant, antiatherosclerosis, anti-inflammatory, antimutagenic, antitumor, and antiviral activities (Jurendić and Ščetar, 2021). Herbal tea has the potential to scavenge free radicals from sticking together (Prajapati et al., 2022) because of its low tannin content. The tea contains a high concentration of polyphenols (Shao et al., 2018). According to McGraw et al. (2007), herbal tea is a healthier beverage as it does not contain caffeine and pyridoxine compared to tea.

Abiotic and biotic stresses such as light intensity, temperature, water availability, type, and soil composition have an impact on the productivity and the quality attributes of herbal teas (Akula and Ravishankar, 2011). Environmental stresses which include inappropriate radiation or temperature as well as drought trigger the over-production of reactive oxidative species (ROS), which involves superoxide (O_2-), singlet oxygen ($\bullet O_2$), hydroxyl ion (OH–), and H_2O_2 (Smirnoff, 1993). Hence, plants can potentially divert their photosynthetic resources to defense mechanisms against detrimental environmental factors to promote vegetative (biomass) and reproductive stages (secondary metabolites) (Wahid et al., 2007; Pezzani et al., 2017). Therefore, herbal teas use secondary metabolites as defense mechanisms to scavenge and detoxify ROS using enzymes such as CAT, peroxidase or superoxide dismutase and decompose H_2O_2 to H_2O at different cellular locations.

Currently, the vast majority of herbal teas are still collected in the wild for various medicinal attributes and variation in quality characteristics is of great concern. According to reports, seasonal variations as well as varying climatic conditions affect the quality of herbal teas throughout the year (Ghasemzadeh et al., 2010; Mudau and Makunga, 2018). Carbon-based secondary metabolites have been discovered to increase in *Labisia pumila* plants only when climatic conditions promote the production, accumulation, and partitioning of non-structural carbohydrates (Ibrahim et al., 2011). There is a need for the domestication of herbal teas for commercialization as a healthy beverage to protect the plants from becoming extinct (Mashimbye et al., 2006) and maximize the quality of secondary metabolites (Mudau et al., 2006). Previous studies have documented four major factors that affect parameters that determine quality in herbal tea production, namely: environmental conditions (Tshivhandekano et al., 2013; MacAlister et al., 2020; Ramphinwa et al., 2022), cultural practices (Yilmaz et al., 2004; Mudau et al., 2006; Hlahla, 2010; Bandara, 2012; Mphangwe, 2012; Mohale et al., 2018), cultivars (Owuor et al., 2000) and seasonal variation (Mudau and Makunga, 2018). Thus, environmental factors and agronomic practices have an impact on the quality parameters of tea (Zhang et al., 2014).

Although drinking black, green, and oolong tea (*Camellia sinensis*) has been linked to various health advantages, there is relatively little research on the effects of most herbal teas. Despite being particularly rich sources of polyphenols, recommendations for the intake of plant-based beverages such as herbal teas are still lacking. Recently, Malongane et al. (2017), claimed that polyphenolic compounds in herbal tea might have synergistic potential, which aids in managing medical conditions when used alongside conventional medicines. The present review gathers data on eco-physiological response of secondary metabolites of herbal tea to better understand the interrelationships between herbal tea and health considering the shift toward integrated medicine and increased interest in herbal tea and health. Drinking herbal tea has been linked to some therapeutic and preventative advantages and this is according to a new scoping review that compiled data from 21 studies, including observational studies (Poswal et al., 2019).

The overall main objective of the present work is to provide a review of production, health benefits and antioxidant properties and how eco-physiological parameters and environmental factors influence accumulation and distribution of secondary metabolites of herbal tea. Thus, the use of locally available herbal plants to develop new herbal tea or infusion could have a significant socio-economic impact on the herbal tea producers in terms of job creation, introducing the product into local and international market as well as improved nutrition and health of consumers since herbal tea is rich in secondary metabolites. Therefore, there is a need to develop strategies to optimize biotic and abiotic factors to promote effective secondary metabolites on a large scale of herbal tea production.

Methodology

The methodology of the current study is divided into four phases to achieve the research objectives, viz: definition of key terms, a mixed methods review to determine the current state of herbal teas and identify gaps in their mainstreaming, a review to quantify the amount of knowledge on how light, shading, season, soil composition, and temperature affect secondary metabolite accumulation in herbal teas. The following sections outline the details of four different stages.

Phase 1: Definitions of key phrases.
Four definitions have been used in this article to describe herbal tea's medicinal properties and functions. Key phrases to be defined include herbal teas, medicinal plants, antioxidants, and polyphenols. Original papers and review articles have been used to gather information to describe the key terms.
Phase 2: Identifying medicinal properties and their functions in herbal teas. Google was used throughout the study to gather information.
Phase 3: Identifying bioactive compounds and their functions in herbal teas.
Phase 4: A mixed-method review approach including quantitative and qualitative research has been used in this phase to gather information about production, processing, biological activities and how environmental factors affect the accumulation of secondary metabolites of herbal teas.

Search strategy

This section was created using a two-step approach to provide an in-depth assessment of herbal teas' nutraceutical, medicinal properties, and priorities.

First stage: Planning the review

Research questions were developed in this stage and were as follows:

1. The current review aims to gather information about nutraceutical properties and environmental factors that influence the quality of herbal teas.
2. What are the medicinal and antioxidant characteristics of herbal teas?
3. Which bioactive compounds are related to the functional characteristics of herbal teas?
4. How do environmental factors affect the quality of herbal teas?

The second stage: A review

Information about the nutraceutical and medicinal benefits of herbal teas was collected through reviewing different research articles. The main objective was to identify herbal teas' medicinal properties and bioactive compounds. Therefore, it was significant to include nutraceutical and medicinal properties attributes of herbal teas. Different attributes identified included: *antimicrobial, antioxidant, hepatoprotection, anti-allergy, antigenotoxic, antiplasmodial, cytotoxic, antispasmodic, cardioactive, anticough, anti-diabetic, anti-inflammatory and antinociceptive, antifungal, toxicological, anti-diabetes, anti-cancer, antinociceptive, antimelanogenic, wound healing, memory enhancing, antibacterial, antimycotic, antitumor, antiviral, gastrointestinal protective, hepatoprotective, and chemopreventive, anti-diarrhea, neuro-protective, anti-allergic, improves cardiac health antiseptic and stimulant, antimicrobial, sedative properties, anti-cholesterol, anti-hypertensive, analgesic, chemoprotective activities and anti-aging.*

Results and discussion

Definitions of key phrases

Herbal teas are an aqueous mixture of different plant materials in hot or cold water to extract the phytochemical constituents for an unspecified period. They are a popular worldwide beverage and are utilized as a therapeutic vehicle in different forms of traditional medicine (Poswal et al., 2019).

A medicinal plant contains active compounds or therapeutic properties in one or more organs that can benefit the human body pharmacologically (Rasool Hassan, 2012; Namdeo, 2018). Since prehistoric times, medicinal plants, also known as medicinal herbs, have been discovered and used in traditional medicine practices. These herbs are preferred by non-industrialized societies, owing to their lower cost compared to modern medications.

Antioxidants are groups of compounds that act in the cell to neutralize free radicals and reactive oxygen species (ROS) (Göçer et al., 2013; Çakmakçi et al., 2015). A free radical is a highly charged and unstable carbon or oxygen atom with an unpaired electron. Lipids, proteins, and carbohydrates may all produce free radicals.

Polyphenols are secondary metabolites produced by higher plants that have potential health benefits for humans, primarily as antioxidants, anti-allergic, anti-inflammatory, anticancer, antihypertensive, and antimicrobial agents (Fraga et al., 2019). They are essential in plant-pathogen and animal defense, herbivore aggression, and stress response to a wide range of biotic and abiotic stressors.

Characteristics of searched literature

Diversity of functional herbal teas

The research study listed 26 herbal teas belonging to 17 different species sampled worldwide (Table 1). The regions were presented by the sampled articles which include South Africa (0.15%), Africa (0.04%), South America (0.04%), South-East America (0.04%), South East Asia (0.12%), Algeria (0.04%), Germany (0.04%), Asia (0.15%), Europe (0.08%), North America, India, South-East Europe, Asia, Mexico (0.04%), Euro Siberian (0.04%), Irano Siberian (0.04%), North Asia, Saudi Arabia, East Europe (0.04%), North Asia (0.04), China (0.04%), South India (0.04%), and Sri-Lanka (0.04%).

Processing of herbal teas

Total concentration of polyphenol, antioxidants and tannin content of herbal tea have been reported to be determined by extraction conditions, variety, extracting solvent and processing methods (Villa-Rodriguez et al., 2018; Vural et al., 2020). Differences in chemical constituents and biological activity of plant products are caused by different processing methods and determining how to assess the impact of post-harvest treatment. Chemical and biological testing are essential for improving the quality control of herbal tea products (Chao et al., 2017). However, Turkmen et al. (2009), discovered the high concentration of polyphenols and antioxidants activity on black tea when extracted over extended period using aqueous acetone compared to lower concentration of polyphenols and antioxidant which were influenced by short period of time during extraction using absolute acetone.

Drying is a thermal process in the production of herbal teas which may result in significant losses of bioactive ingredients, reducing the health benefits and quality of the products (Mbondo et al., 2018; Monika and Selvakumar, 2019). The content of the desired components in tea infusion may be affected significantly by the brewing conditions such as quality, volume, and temperature of water and brewing time (Nikniaz et al., 2016; Sharpe et al., 2016).

Polyphenols of herbal teas

Different polyphenols substances, such as flavonoids, tannins, phenolic acids, chlorogenic acids etc., have been reported in herbal teas; however, different parts of herbal teas react differently to different polyphenols (Table 2). Herbal teas have medicinal attributes due to their high concentration of polyphenols (Koch et al., 2020), which is well known to have a wide range of advantageous biochemical and physiological properties (Koch et al., 2020; Afrin et al., 2022). Herbal teas use these bioactive compounds as their

TABLE 1 Different types of herbal teas used globally.

Common name	Scientific name	Family	Country	Parts used	Reference
Bush tea	*Athrixia Phylicoides*	Asteraceae	South Africa	Leaves, roots, and flowers	Mudau et al., 2016; Mohale et al., 2018; Ramphinwa et al., 2022
Special tea	*Monsonia burkeana*	Geraniaceae	South Africa	Roots and leaves	Mamphiswana et al., 2010; Nnzeru et al., 2016; Mfengu et al., 2021
Honeybush	*Cyclopia (Vent.) spp*	Fabaceae	South Africa	Shoots, stems and leaves	De Beer et al., 2021
Rooibos	*Aspalathus linearis*	Fabaceae	South Africa	Leaves	Joubert and Schultz, 2012; Gaggìa et al., 2018
Fever tea	*Lippia javanica*	Verbenaceae	Africa	Leaves, twigs and sometimes roots	Mkwanazi et al., 2021
Blackjack	*Bidens Pilosa*	Asteraceae	South America	Leaves and stem	Liang et al., 2016; Bilanda et al., 2017
Misai kucing	*O aristatus*	Lamiaceae	South-East Asia	Leaves	Hui Gan et al., 2017
Lemongrass	*C. citrastus*	Poaceae	Algeria	Leaves	Olayemi, 2017
Guajava	*P. guajava*	Myrtaceae	Asia	Leaves	Angulo-López et al., 2021
Lemon myrite	*Backhousia citriodora*	Myrtaceae	Germany	Leaves	Kim et al., 2017
Bitter gourd	*Mormodica charantia,*	Cucurbitaceae	Asian	Leaves	Muronga et al., 2021; Ramabulana et al., 2021
Mas cotek	*Ficus deltoidei*	Moraceae	South-East Asia	Leaves	Nasma et al., 2018
Pegaga	*Centella asiatica*	Apiaceae	South-East Asian	Leaves	Nazmi and Sarbon, 2020
Peppermint	*Mentha piperita*	Lamiaceae	Europe	Leaves	Bodalska et al., 2019
Mint	*Mentha spicata*	Lamiaceae	Europe, North America and Asia	Leaves	Yu et al., 2015
Chamomile	*Matricaria recutita*	Asteraceae	Southern and Eastern Europe	Leaves	Gupta et al., 2010; Bayliak et al., 2021.
Oregano	*Origanum vulgare*	Lamiaceae	Mediterrenian, Euro-Siberian and Irano-Siberian	Leaves, flowers, roots and stems	Han et al., 2017
West Indian lemongrass	*Cymbopogon citratus*	Poaceae	South-East Asia	Leaves	Kamaruddin et al., 2021
Roselle	*Hibiscus sabdariffa*	Malvaceae	India and Saudi Arabia	Leaves, flowers and seeds	Da-Costa-Rocha et al., 2014
Indian gooseberry	*Phyllanthus amarus*	Phyllanthaceae	India	Leaves	Zhao et al., 2015
Guava	*Psidium guajava and Taona sinensis*	Myrataceae	Mexico	Leaves and roots	Angulo-López et al., 2021
Akar ketuau	*Thunbergia laurifolia and Orthosiphon aristatus*	Acanthaceae	India	Leaves	Boonyarikpunchai et al., 2014
Red raspberry	*Rubus idaeus* L	Rosaceae	Eastern Europe and North Asia	Leaves	Singh et al., 2020
Astragalus tea			China	Leaves	
Ginger tea	*Zinger officinale* Roscoe	Zingiberaceae	Asia	Rhizomes and leaves	Gbenga-Fabusiwa et al., 2018
Cardamom tea	*Elettaria cardamomum*	Zingiberaceae	South India and Sri-Lanka	Seeds	Anwar et al., 2016

defense against environmental stresses, herbivores, and pathogen attack. Hence, the nature of growing conditions and the amount of stress that the plant is subjected to, determine the concentration of secondary metabolites (Akula and Ravishankar, 2011; Mohale et al., 2018). Polyphenols of herbal teas are found on leaves, flowers, twigs, roots, and rhizomes.

Bush tea has been reported to contain 5-hydroxy-6,7,8,3′,4′,5′-hexamethoxy flavon-3-ol (Mashimbye et al., 2006), 3-0-demethyldigicitrin, 5,6,7,8,3′,4′-hexamethoxyflavone, and quercetin, as well as other polyphenols, tannins, and antioxidants (Mudau et al., 2006, 2007a; Tshivhandekano et al., 2018). The special tea' leaves and fruits has been reported to have high

TABLE 2 Different types of herbal teas and their health functions.

Herbal teas	Available antioxidants	Functions	References
Bush tea	Flavonoids, polyphenols and tannins	They protect against inflammation, cardiovascular disease, cancer, and the aging process. Tannins bind to iron and reduce non-heme iron absorption.	Mudau et al., 2006 Mudau and Makunga, 2018
Special tea	Polyphenols and tannins	They serve as antioxidants and antimicrobial	Ngoepe et al., 2018
Honeybush	Hesperidin and eriocitrin flavanones, as well as scolymoside flavone	They have anti-diabetic, anti-cancer, anti-obesity, antioxidant, and antimicrobial properties	De Beer et al., 2021
Rooibos	Polyphenols (aspalathin, nothofagin; free flavones and glycosides: orientin, iso-orientin, vitexin, isovitexin, luteolin, luteolin-7-O—D-glucoside) flavonols and glycosides (quercetin, hyperoside, rutin)	It has antioxidant properties, antimutagenic properties, and the ability to lower blood glucose levels.	Joubert and Schultz, 2012; Gaggìa et al., 2018
Fever tea	Monoterpenoids (myrcene, caryophyllene, linalool, p-cymene, and ipsdienone); stearic, palmitic, myristic, oleic, arachidic, behenic, and lignoceric acids, as well as triacontane alkanes and Iridoid glycosides, and highly toxic triterpenoids (acerogenins)	It has antimalarial, antiviral, cytostatic activities, and antimicrobial properties	Endris et al., 2016
Blackjack	Aliphatics, terpenoids, tannins, alkaloids, hydroxycinnamic acid (HCA; and phenylpropanoids are all constituents of blackjack	It has anticancer, anti-inflammatory, and antihypertensive properties.	Ramabulana et al., 2020
Misai kucing	Phenolic acids, terpenoids (diterpenes and triterpenes; flavonoids and benzochromenes Phenolic compounds, such as caffeic acid, rosmarinic acid, sinensetin, and eupatorine	It possesses antioxidant, anti-inflammatory, and antihyperglycemic	Pang et al., 2017; Abdullah et al., 2020
Lemongrass	Flavonoids and tannins	It contains antimicrobial activity properties	Olayemi, 2017
Guajava	Phenolic, flavonoid, carotenoid, terpenoid and triterpene	It has antioxidant, hepatoprotection, anti-allergy, antimicrobial, antigenotoxic, antiplasmodial, cytotoxic, antispasmodic, cardioactive, anticough, antidiabetic, anti-inflammatory and antinociceptive properties (Joseph, 2013)	Angulo-López et al., 2021
Lemon myrite	Phenolic acids and flavonoids	It serves as antimicrobial, antifungal and toxicological activities	Hayes and Markovic, 2002; Kim et al., 2017
Bitter gourd	Cucurbitane triterpenoids, saponin glycosides, chlorogenic acids and flavonoids	It consists of anti-diabetes, anti-cancer, and anti-inflammatory properties	Dandawate et al., 2017
Mas cotek	flavonoids isovitexin, vitexin proanthocyanidins, flavan-3-ol monomers and flavones glycosides	It has anti-diabetic, antinociceptive ulcer healing, antioxidant, anti-inflammatory, antimelanogenic properties	Nasma et al., 2018
Pegaga	Polyphenol, flavonoid (3-carotene, tannin, vitamin C, and DPPH (2, 2-diphenyl-1-picrylhydrazyl).	It has antioxidant, anti-inflammatory, wound healing, memory-enhancing properties	Singh et al., 2015
Peppermint	Phenolic and flavonoids	It has antioxidants, antiallergenic, antibacterial, anti-inflammatory, antimycotic, antitumor, antiviral, gastrointestinal protective, hepatoprotective and chemo preventive properties	Bodalska et al., 2019
Chamomile	Phenols and flavonoids	It has anti-inflammatory, anti-diarrhea, antioxidant, anti-cancer, neuroprotective, anti-allergic and antimicrobial properties and improves cardiac health	Ašimović et al., 2022
Oregano	Coumarins and phenylpropanoids	Possesses antiseptic and stimulant	Han et al., 2017
West Indian lemongrass	Alkaloids, saponins, tannins, anthraquinones, steroids, phenols and flavonoid	Antimicrobial, anti-inflammatory, and sedative properties	Kamaruddin et al., 2021
Roselle	Flavonoid, tannin, and a phenolic compound	It contains anti-cholesterol, anti-diabetic and anti-hypertensive properties.	Abdullah et al., 2020
Indian gooseberry	Phenolic compounds and Vitamin C	It has anti-inflammatory, antioxidant, and chemoprotective properties.	Zhao et al., 2015
Red raspberry	Polyphenols (anthocyanins and ellagitannins contents).	It exhibits antioxidant properties	Singh et al., 2020
Ginger tea	Flavonoids and phenolics	It has antioxidant, anti-aging, and anti-cancer properties.	Huyen, 2020

concentration of total phenolic compound and total antioxidant activity (Mamphiswana et al., 2010; Suleman et al., 2022; Mfengu et al., 2021). The unfermented leaves of honey bush tea have been discovered to contain polyphenol compounds which include pinitol, shikimic acid, p-coumaric acid, 4-glucosyltyrosol, epigallocatechin gallate, the isoflavone orobol, flavanones hesperedin, narirutin, and eriocitrin, a glycosylated flavan, the flavones luteolin, 5-deoxyluteolin, and scolymoside, the xanthone mangiferin, and the flavonol C-6-glucosylkaempferol (Dube et al., 2017; Ajuwon et al., 2018). Rooibos has been characterized by a diverse range of phenolic compounds, including dihydrochalcones (aspalathin, aspalalinin, and nothofagin), flavones (orientin, iso-orientin, vitexin, isovitexin, chrysoeriol, and luteolin), flavonols (quercetin, isoquercitrin, hyperoside, and rutin), and phenolic (Ajuwon et al., 2018). Fever tea has been reported to have volatile oil as well as various monoterpenoids which include myrcene, caryophyllene, linalool, p-cymene and ipsdienone (Mokoka, 2007; Endris et al., 2016).

Endris et al. (2016) and Chawafambira (2021), discovered that leaves of fever tea produce numerous polyphenolic compouds such as of stearic, palmitic, myristic, oleic, arachidic, behenic, and lignoceric acids and triacontane alkanes. *Misai kucing* possess pharmacological properties due to the presence of different groups of phenolic acids including terpenoids (diterpenes and triterpenes) (Abdullah et al., 2020), flavonoids (Pang et al., 2017), and benzochromenes (Abdullah et al., 2020). Lemon grass possess different compounds as hydrocarbon terpenes, alcohols, ketones, esters due to different geographical origin (Majewska et al., 2019). Guajava contains significant biological activities caused by the presence of phenolic, flavonoid, carotenoid, terpenoid and triterpene (Angulo-López et al., 2021).

The high levels of antioxidant activity influenced by phenolic compounds contents as phenolic acids and flavonoids are found on the leaves of lemon myrite (Kim et al., 2017). Triterpene, proteid, steroid, alkaloid, inorganic, lipid, and phenolic compounds are the major compounds of bitter gourd which are responsible for antidiabetic activities (Grover and Yadav, 2004; Chung et al., 2018). Mascotek has been characterized by various phenolic compounds including flavonoids, saponins, tannins, steroids, and terpenes (Nasma et al., 2018). Peppermint has been discovered to possess flavonoids such as flavanone aglycone eriodictyol and glycosides eriocitrin (eriodictyol-7-O-rutinoside), hesperidin (hesperetin-7-O-rutinoside) and naringenin-7-O glucoside, the flavone aglycone luteolin and the glycosides isorhoifolin (apigenin-7-O-rutinoside) and luteolin-7-O-glucoside (Bodalska et al., 2019). The extract of pegaga consist of bioactive compounds such as plant sterols, flavonoids, and other components with no known pharmacological activity (Nazmi and Sarbon, 2020).

Chamomile have been reported to contain numerous bioactive phenolic compounds which are coumarins: (herniarin, umbelliferone; phenylpropanoids: chlorogenic acid, caffeic acid; flavones: apigenin, apigenin, 7-O-glucoside, luteolin, luteolin-7-O-glucoside; flavonols: quercetin, rutin, and flavanone: naringenin) and are found in chamomile extract (Gupta et al., 2010; Bayliak et al., 2021). The major compounds of oregano are caryophyllene, spathulenol, germacrene-D, and aterpineol (Sahin et al., 2004). The volatile oil from *Cymbopogon citratus* consist of volatile oil which is characterized by monoterpene hydrocarbons (Adesegun et al., 2013; Oladeji et al., 2019). The fraction of monoterpene has been classified by a high percentage content of geranial (39.53%), neral (33.31%), myrecene (11.41%), and other sesquiterpene (0.78%) (Wright et al., 2009; Moreira et al., 2010).

Da-Costa-Rocha et al. (2014), discovered that the extracts of roselle consist of a high percentage of organic acids, including citric acid, hydroxycitric acid, hibiscus acid, malic and tartaric acids as major compounds, and oxalic and ascorbic acid as minor compounds. Goose berry extracts are rich source of polyphenols which are responsible for cytotoxic activity against cervical and ovarian cancer cells (De Wet et al., 2012). Red raspberry possesses two major polyphenols such as anthocyanin and ellagitannins content (Singh et al., 2020). Ginger is a rich source of phenolic components which are important food material and can be served as cheap (Gbenga-Fabusiwa et al., 2018).

Biological activities of herbal teas

Medicinal properties of herbal teas are summarized in Table 2 and has been reported by different researchers.

Antioxidant activity

Herbal teas, which are herb extracts, are popular because of their fragrance and antioxidative properties (Aoshima et al., 2007; Farzaneh and Carvalho, 2015; Jin et al., 2016). Antioxidants are substances that have been shown to significantly neutralize reactive oxygen species (ROS), which are oxygen-derived free radicals that cause degenerative diseases such as superoxide anion, hydroxyl radicals, and nitric oxides (Malongane et al., 2017). *In vitro* studies revealed that ethanolic bush tea extract has strong antioxidant activity and inhibition of DPPH was found to be 81.6% when the lowest concentration was used to test antioxidant activity (Mavundza et al., 2007). Moreover, Bahadori et al. (2020) demonstrated that *Stachys byzantina* and *Stachys iberica* exhibited DPPH scavenging activity ranging from 26 to 125 mg TE/g extracts.

Antidiabetic activity

According to Martínez-Solís et al. (2021), diabetes mellitus has been treated by herbal teas and infusions. Diabetes mellitus is a chronic condition in which the body's ability to control the amount of glucose in the blood is impaired (DeFronzo et al., 2015). This is due to pancreatic insulin resistance or a lack of insulin secretion. Phenolic compounds in herbal teas such as chlorogenic acid, 1,3-dicaffeoylquinic acid, and hydroxylcinnamic acid, have been linked to diabetes and obesity prevention (Joubert and Schultz, 2012). Chellan et al. (2012) reported that herbal teas could be used to treat metabolic irregularities associated with diabetes by increasing glucose utilization in insulin-responsive tissues. Previous studies have also demonstrated anti-diabetic, antioxidant, antilipidemic, and antinociceptive effects using aqueous and alcoholic extracts of *Annona muricata*, *Annona squamosa*, *Annona stenophylla*, *Annona macroprophyllata*, and *Annona diversifolia* and this is attributed to the presence of phenolic compounds in their leaves (Martínez-Solís et al., 2021).

Antimicrobial activities

Herbal teas have been reported to have antimicrobial activities against gram-positive and -negative bacteria and yeast when they are used alone (Hacioglu et al., 2017). Depending on the antibiotic or type of tea, the synergistic, additive, or antagonistic effects of herbal teas with antibiotics were observed. Thus, using herbal teas alone or in combination with chemical antimicrobials may be a viable alternative treatment strategy for a wide range of pathogenic microorganisms. Generally, antimicrobial activities decrease with the extent of tea fermentation, implying that green tea is more active than black tea (Nibir et al., 2017). Green tea catechins, particularly epigallocatechingallate (EGCG) and epicatechingallate (ECG), have antibacterial properties against Gram-positive and Gram- bacteria negative bacteria (Bancirova, 2010; Ignasimuthu et al., 2019).

Green tea can help prevent tooth decay by inhibiting oral bacteria (Zayed et al., 2021). Xia et al. (2021) discovered that combining white tea and pepper mint resulted in synergistic antibacterial activity against four strains, two of which were gram-positive (*S. argenteus* and *B. halotolerans*) and two of which were gram-negative (*E. coli* and *P. aeruginosa*). Bush tea inhibits microorganisms such as *Staphylococcus aureus, Bacillus cereus, Enterococcus, Escherichia coli,* and *Mycobacterium smegmatis*.

Anti-mutagenic/anti-carcinogenic activities

The antimutagenic assay revealed that unfermented rooibos and honey bush tea extracts had a strong antimutagenic effect against both metabolically activated carcinogens, antimutagenic activity against 2-acetylaminofluorene (2-AAF) and (aflatoxin) AFB1 (Marnewick et al., 2000; Chaudhary et al., 2021). Carabajal et al. (2017), also discovered that antimutagenic activity of the freeze-dried plant infusions tested against a direct-acting mutagen (4-NPD), with at least three herbal mixtures resulting to a positive response.

Environmental factors that affect the production and accumulation of secondary metabolites of herbal teas

Abiotic and biotic factors, including ultraviolet irradiation, high light, temperature, pathogen attack, wounding, herbicide, and nutrient deficiency have been reported to determine the concentration of different metabolites in herbal plants (Akula and Ravishankar, 2011; Mohale et al., 2018). Plants are a rich source of natural compounds with diverse bioactivities (Masike et al., 2017). These organic compounds are divided into two categories: primary and secondary metabolites and used by plants as defense mechanisms against biotic and abiotic (Akula and Ravishankar, 2011; Mohale et al., 2018). The quality of herbal teas remains one of the constant critical aspects in determining tea's price (Ravichandran and Parthiban, 1998; Tshivhandekano et al., 2018), industrialization, and exportation (Mudau et al., 2007b). Herbal tea's quality is determined by active secondary metabolites present, viz., flavonoids, polyphenols, and tannins (Mathivha et al., 2020). Thus, compounds such as polyphenols, flavonols, and tannins are the main indicators of the medicinal potential of herbal teas due to their antioxidant activities (Hirasawa et al., 2002; Mudau et al., 2007b; Poswal et al., 2019).

Light

Light is a critical resource for plants (Ghasemzadeh et al., 2010; Rihan et al., 2020) and competition for light under shade affect growth and development of herbal teas (Kumar et al., 2013a; Ramphinwa et al., 2022). Plant growth and development, photosynthetic rate, and production of both primary and secondary metabolites are all influenced by light (Zhang et al., 2014). Currently, the light requirements of herbal teas are not well documented. Although it is difficult to define details of the ideal range of shadow required by tea plants, 50% of diffused sunshine is generally necessary for optimal physiological activity of Camellia sinensis tea (den Braber et al., 2011; Tshivhandekano et al., 2013). Shade/low irradiance enhances flavonoid synthesis and other bioactive compounds in ginger production (Ghasemzadeh et al., 2010).

Photosynthetically Active Radiation (PAR) is a waveband that has a significant influence on plants' growth, development (Proutsos et al., 2022) and accumulation of secondary metabolites (Ghasemzadeh et al., 2010). It is also known as the intercepted radiation that ranges between 400 to 700-nanometre wavebands (Mubvuma, 2018; Rihan et al., 2020). Appropriate intercepted radiation and utilization are of great importance in herbal tea production. Bush tea plants exposed to 80% white shade net accumulated more chlorogenic acid (CGAs) than plants exposed to other shade nets (i.e., 80% black, green shade nets and full sunlight) (Ramphinwa et al., 2022). These results could be attributed to the accumulation of CGAs caused by low temperatures and light intensities under 80% white shade net. The white shade net might have induced a higher number of chlorogenic acids than other shade nets due to the amount of light penetrating it. These findings are consistent with those of Karimi et al. (2013), who found that when different varieties of *Labisia pumila* Benth are exposed to high light intensities, tend to accumulate more phenolic compounds such as gallic acid, caffeic acid, and flavonoids such as quercetin, rutin, myricetin, kaempferol, and naringin.

Contradictory, higher oxygenated monoterpene and sesquiterpene components such as citronellol, geranyl acetate, linalool and trans-rose oxide were recorded in an open field compared to 25 and 50% shade levels. Kumar et al. (2014) and Rezai et al. (2018), also reported that oxygenated monoterpenes and sesquiterpene components decreased with shade levels in *S. sclarea* and *T. minuta*. Light might have influenced these results as a critical component that plays a significant role in producing secondary metabolites that vary due to the plant's metabolic processes and physiology. Variation of light intensities revealed plant morphological and physiological changes, which significantly impacted the herb's medicinal compounds (Idrees et al., 2018). Therefore, different plants respond differently to light intensity, resulting in differences in secondary metabolite production (Ibrahim et al., 2011; Ni et al., 2020).

Herbal plants utilized in traditional therapeutic techniques are frequently produced in places with significant UV exposure, and there are no defined conventional agricultural practices (Makola et al., 2016a). In such conditions, photoisomerization reactions of bioactive compounds are expected to be simple, putting active molecules at risk. As a result, it is critical to investigate the environmental effects of plants with therapeutic properties. Plants naturally produce cinnamic acids in a trans-configuration, which changes to a *cis* configuration when exposed to UV light (Makola et al., 2016b). These results concur with those of Masike et al. (2017) and Nobela et al. (2018), who reported the increasing of the content of secondary metabolites containing cinnamic acids through UV light. Chrysanthemum's concentrations of flavonoids and phenolic acids increased in response to increased UV-B radiation (Ma et al., 2016). These results might have been attributed to an increase in UV radiation associated with the amount of solar radiation received by the plants (Naghiloo et al., 2012).

Shading

Plant shading is caused primarily by dense plant populations, intercropping, planting geometry, and excessive vegetative growth, and it has an impact on crop performance by reducing plant photosynthetic capacity (Kumar et al., 2013b; Zaman et al., 2022). Irradiance is one of the crucial environmental factors that affect many physiological processes in plants, such as plant growth and development, reproduction, and distribution of secondary metabolites (Kumar et al., 2013a; Zhang et al., 2015). Photoselective films, which regulate light conditions and influence medicinal plant growth and secondary metabolism, are important for optimizing secondary metabolite accumulation (Khandaker et al., 2010; Grbic et al., 2016). Black tea exposed to artificial shade resulted in a higher concentration of theaflavin, lower concentration of thearubigin, higher flavor index and taster's evaluation compared to tea grown in an open field. This hypothesis holds that removing the shade from tea gardens results in a loss of quality (Owuor et al., 1988; Zaman et al., 2022).

These findings concur with those of Morita and Tuji (2002), who reported that shading produces high-quality Gukyo and Tencha green teas in Japan. The results might have been influenced by low light intensity under shades. Hence, shading could define tea's characteristics by slowing the photosynthesis process and thus increasing the chlorophyll content (Lehlohonolo et al., 2013). These might be due to the leaves that turn dark green, and the tannin content decreases, resulting in a sweeter flavor rather than the astringent taste common in green teas under shades. These results contradict with Kumar et al. (2013b), who reported that shade regimes did not affect the accumulation of stevioside and Rebaudioside-A in the stevia plant. Thus, accumulation and partitioning of the secondary metabolite are impacted by plant species, different plant organs, and environmental conditions to which the plants are subjected (Eko et al., 2012; Mohd Yusof et al., 2021).

Seasons

Producing tea of the same quality is impractical throughout the year due to different climatic conditions and seasonal variations (Owour and Obanda, 1998; Mudau et al., 2007a, 2016). The results are in line with those of Lin-Wang et al. (2011), who reported that significant climatic changes throughout the cropping season have a significant impact on tea quality and value. These findings might have been influenced by harsh climatic conditions, which are unsuitable for producing high-quality herbal tea (Mudau et al., 2016). According to Mudau et al. (2006), variation in seasonal temperatures and vapor pressure deficit affect the quality and antioxidants in bush tea. The concentration of polyphenols in bush tea leaves collected from the wild has been recorded to be lowest in autumn, spring and highest in winter (Mudau et al., 2006; Nchabeleng et al., 2012).

Furthermore, hydrolysable tannins concentration was lowest during summer compared to autumn, spring and winter. The results might have been attributed due to drought stress (Hamilton et al., 2001; Lv et al., 2021) and low temperatures (Mudau et al., 2006) during autumn and winter. The results are in line with those of Caruso et al. (2020), who reported the highest value of hydrophilic antioxidant activity under unshaded fields, but there was no significant difference between autumn and winter cropping seasons; hence lowest was recorded in the last cropping season.

Turkmen et al. (2009) and Soni et al. (2015), further reported variation of catechin content and distribution in fresh tea leaves are influenced by harvesting season. Similar results were also discovered by Chou et al. (1999) and Salman et al. (2022), who reported that catechin content variation due to harvesting season and higher antimicrobial activity during summer cropping season resulted in a higher concentration of catechin. In Australia, higher epicatechin gallate (ECG) and epigallocatechin gallate (EGCG) levels were recorded during warmer months (Yao et al., 2005; Kashchenko et al., 2021), while EGC recorded higher levels in cooler months. As a result, the warmer season is recommended for producing high-quality black tea (Lin et al., 1996; Hossain et al., 2017). Understanding the metabolic process of herbal teas will elucidate how the variation of seasons may impact the formation and its quality.

Temperature

The effect of temperature on plant biosynthesis and phytochemical accumulation is significant (Cheynier et al., 2013; Pola et al., 2020). The physiological and biochemical processes that result in the formation of plant metabolites are influenced by temperature (Tshivhandekano et al., 2013). Low temperature restricts the accumulation of alkaloids (morphinane, phthalisoquinoline and benzylisoquinoline) in dry *Papaver somniferum*) (Yang et al., 2018). Similarly, Dutta et al. (2007) and Jan et al. (2021), reported the reduction of vindoline and catharanthine levels in *Catharanthus roseus* leaves due to low temperatures. Contradictory, different cultivars of *Lupinus angustifolius* increased accumulation of alkaloid when exposed to high temperature. Thakur et al. (2019), also reported that higher temperatures promote leaf senescence and concentration of the secondary metabolite in the roots of *Panax quinquefolius*.

Soil type and composition

The production, accumulation, and partitioning of secondary metabolites in plants have been reported to rest on a few hypotheses: carbon nutrient balance (CNB) and growth differentiation. Verma and Shukla (2015) discovered that plant growth and cell development take precedence over secondary metabolite production. Before distributing carbon and nitrogen to produce secondary metabolites, the growth requirement must be met. Nutrient-deficient in plants promotes a higher concentration of carbon-based secondary metabolites at the expense of plant growth and development than plants with enough nutrients (Radušiene et al., 2019). These findings imply that herbal tea could accumulate more secondary metabolites when plants are deprived of nutrients.

The most important determinant of the rate of secondary metabolite production is the collection of precursor molecules (Waterman and Mole, 2019). As a result, it suggests that the status of carbon-nutrient balance in plants, as determined by resource availability, has a significant influence on secondary metabolite allocation. Hence, the palatability and resistance of the plant to herbivores are affected by the allocation of secondary metabolites. The more nitrogen is invested in soil, the less the accumulation of phenolics and flavonoids in *Labisia pumila* Benth (Ibrahim et al., 2011). Contradictory, previous studies reported that N shortage increased the content of carbon-based secondary metabolites (CBSMs) (e.g., polyphenols, flavonoids, and triterpenoids) (Ibrahim et al., 2013; Strzemski et al., 2021; Sun et al., 2021).

Water stress

Water stress is one of the most important environmental stresses affecting plant morphological growth and development and their biochemical properties (Ashraf et al., 2018). It can increase the accumulation of secondary metabolites in a wide range of plant species. Endogenous levels of plant secondary metabolites increased in response to drought stress in several medicinal plants, including *C. roseus, H. perforatum,* and *Artemisia annua*. Drought stress, for example, increased phenolics and photosynthetic pigments while decreasing plant fresh and dry biomass in *T. ammi* (Azhar et al., 2011). Similar results were reported by Verma and Shukla (2015), that improved quality of secondary metabolites such as rutin, quercetin, and betulinic acid in *Hypericum brasiliense, Artemisinin* and *Artemisia* resulted in water stress. Contradictory, essential oil content (%) and yield decrease significantly with increasing the level of water stress in *Origanum vulgare* and *Melissa officinalis* (Said-Al Ahl and Hussein, 2010). Drought tolerance in plants differs from species to species (Thakur et al., 2019).

Limitation and future perspective of herbal teas

Over the past two decades, the safety and medicinal potency of herbal teas have been subject of interest. Results from different studies show that herbal teas contain phytochemicals that are beneficial while other are toxic to human health (Upadhya, 2004; Krushna et al., 2009; Gohil et al., 2010; Singh et al., 2013). There is a very limited information from the literature with regards to the safety of herbs and herbal teas, herb-herb and interconnections of herb-therapeutic drug (Chandrasekara and Shahidi, 2018). Therefore, there is a need that future research determines the toxicity and bioactivity of herbal teas.

Another challenge of herbal teas is that their market is unstructured and there is risk of poisonous products entering the market. For example, Jin et al. (2018) found 14 poisonous species used for herbal teas in the ethnobotanical surveys of traditional medicinal markets on the Dragon Boat Festival, China. Poor sourcing standards could result in such risk since there might be no quality measurement of original plant materials. Therefore, there is a need for sector to provide products that meet medical standard and not only concentrating on the amount of phytochemicals in the plant materials, but to guarantee quality and reassure consumers that the products are not contaminated (Booker and Heinrich, 2016). Moreover, authors indicated that there might be adulteration of herbal teas in the same market. A recent quality evaluation of marketed chamomile tea found that other plant materials are more likely to adulterate crude flowers than German chamomile tea bags (Guzelmeric et al., 2017).

The labeling and promotion claim for most of herbal teas are questionable, with claims of superior antioxidant activity compared with tea or coffee and the potential to treat various health disorders (McKay and Blumberg, 2007). Such claims should be supported by evidence that is sound and research based (Balentine et al., 1999). Most of these herbal teas have not been well documented especially for studies that involve human trials, therefore, such health benefit claims are not justifiable even though most of these teas have history of utilization in some traditional medicines. Poswal et al. (2019) suggested that there might be relationships between the consumption of herbal teas and low risk of thyroid disease and liver. Therefore, there is a need to conduct further research on analytical and clinical trials to evaluate the phytochemicals of herbal beverages that act in reducing the risk of disease in human as well as verifying how they promote human health (Chandrasekara and Shahidi, 2018).

Other areas of interest include synergistic combination and microencapsulation of herbal teas. Moreover, non-thermal treatments, such as high-pressure processing should also be exploited. The synergistic effect of various combinations of herbal teas has been studied. The mixture of tea with other herbs has demonstrated to synergistically improve antioxidant activities and this leads to the development of various blends of tea blends. The antioxidant activity of the synergistic mixture might offer concomitant health benefit since polyphenolic compounds available in the tea and herbs play role in the prevention of cardiovascular diseases and type 2 diabetes mellitus (Malongane et al., 2017). Mathivha et al. (2020) determined the synergistic effect of South African herbal teas namely bush tea—*Athrixia phylicoides* DC and special tea—*Monsonia burkeana* Planch. Ex Harv and reported that the mixture has high antioxidant activities that might play a role in managing lifestyle diseases such as diabetes (Etheridge and Derbyshire, 2020).

Microencapsulation is an emerging technique which leads to the protection of various components of food or functional ingredients against different processing methods since it covers them inside a polymeric or non-polymeric material and allow their controlled release under specific conditions (Choudhury et al., 2021). Moreover, microencapsulation improves the organoleptic attributes of food by camouflaging the unpleasant smell and taste as well as preventing the growth of microorganisms (Sengupta et al., 2001; Hasanvand et al., 2015). Spray and freeze drying are the extensively used methods for microencapsulation. Pasrija et al. (2015) microencapsulated polyphenolic compounds of green tea with walls of maltodextrin, b-cyclodextrin and combination of both and determined its effect on the quality of bread. Green tea extract and encapsulates added bread maintained their quality characteristics with regards to loaf volume and crumb firmness and they were almost similar to control sample. The total polyphenolic content of extract of green tea and microencapsulated bread did not differ significantly.

High pressure processing (HPP) is applied to food to eliminate vegetative microorganisms, thereby warranting microbial safety and improved shelf life of food (Guerrero-Beltrán et al., 2005). During HPP process, hydrostatic pressure varying from 100 to 800 MPa, is applied to beverages or food which leads to inactivation of microorganism by denaturing protein or cell injury (Guerrero-Beltrán et al., 2005). Moreover, HPP also retains bioactive components such as polyphenols, antioxidant activity and it does not affect small molecules such as pigments, vitamins and volatile compounds (Patras et al., 2009; Medina-Meza et al., 2015; Marszałek et al., 2017).

Kieling and Prudencio (2019) evaluated the quality characteristics of lemongrass-lime mixed beverage processed under the optimal HPP conditions during 8 weeks of storage at 4°C. The beverage was compared with the control and pasteurized sample. High pressure processed beverage retained its phenolic compounds, no significant losses of ascorbic acid observed, and physicochemical properties were closer to control sample compared with pasteurized sample. Moreover, HPP of 250 MPa for 1 min at 25°C resulted in microbiological safety, based on the inactivation tests with *Listeria innocua* as the target microorganism. This shows that HPP can be utilized as an alternative or substitute of thermal processing of herbal teas since it extended the shelf life of lemongrass-lime mixed beverage.

Conclusions

Herbal tea is a rich source of secondary metabolites. Environmental factors have been studied herein to determine their influence on the quality of herbal teas. Generally, abiotic and biotic stresses increase the production, accumulation and partitioning of secondary metabolites on plants at the expense of plant growth, development, and yield. In this study, various examples of herbal teas have been shown to respond differently to secondary metabolites affected by environmental factors. Therefore, this study confirms that different herbal teas' response to environmental factors depends on the type of species, cultivar, and the degree of shade that the plant is exposed to. Quality assurance is a critical step required to be achieved for the potential market for herbal teas. Hence, metabolic processes known to optimize the production of secondary metabolites can thus be achieved by manipulating agronomic practices on herbal teas. It is thus concluded that light, shading, season, soil composition, water stress and temperature play a significant role in cultivating herbal teas. The health benefits of herbal tea necessitate more effort to understand the complex interaction of biotic and abiotic environmental factors with the plant to produce secondary metabolites.

Author contributions

Conceptualization, validation, and writing-original draft preparation: MLR, MEM, and FNM. Methodology: MLR, MEM, NEM, VST, and FNM. Resources and project administration: GRAM, NEM, and FNM. Funding acquisition: MLR, NEM, GRAM, and FNM. Writing-review and editing: MLR, MEM, NEM, GRAM, VGPC, TAM, TM, VST, and FMN. All authors contributed to the article and approved the published version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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