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REVIEW

# Herbal infusion – processing techniques, bioactivity, quality, and safety

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**Abstract**

Botanical remedy, including herbal infusion or tisane, is getting attention from the health-conscious consumer to provide dietary polyphenol/dietary antioxidants. However, some quality and pharmacological aspects of dried herbs used in the tisane or herbal tea are taken for granted and can place the consumer's health and safety at risk. The purpose of this review is to investigate pre-harvesting and post-harvesting aspects of herbal tea that implicate the quality, i.e., therapeutic properties and safety, i.e., toxicity. Selection of botanical origin, agricultural practice, and pharmacological background (pharmacodynamic and pharmacokinetic aspects) of botanical material are the identified vital factors in the pre-harvesting aspects that should be considered before introducing the monoherbal or polyherbal preparation to ensure optimum benefits and safety. Besides the herbal blending preparation, the tea processing standard and drying technique are vital in ensuring the stability of herbal tea and consequently determining the quality of herbal infusion. The variation of processing techniques used and the pharmacological factors of herbal sources have laced on the quality and authenticity issues of herbal infusion and still need further studies to identify the potential health risks to the consumer.

## 1. Introduction

Tea, an infusion of dried *Camellia sinensis* leaves, is the most consumed botanical drink before coffee, chocolate, and fruit drink. It has been a part of universal drinking culture that dynamically evolved over the centuries and diversified according to geographical zone, era, and local culture. Besides its unique flavors, tea can be a versatile ingredient compared to coffee on the market shelves. This versatility is steered by consumer's desire to consume botanical remedies to fight off chronic ailments such as metabolic syndrome (cardiovascular heart disease, diabetes, and blood hypertension), including anti-obesity effects (Dias *et al.,* 2013), which can alleviate allergic rhinitis syndromes (Peiris *et al*., 2019), and benefits health aging by slowing the cognitive decline (Divya and Ashok, 2019). A growing interest in natural products innovation throughout the years has driven tea leaf and its ready-to-drink (RTD) products to be consumed for a variety of health purposes, made either from fermented tea (kombucha) or a mixture of tea leaves with medicinal herbs or the herbs alone known as tisane that specifically target more niche functions.

This review investigated the pre-harvesting and the post-harvesting aspects of herbal tea that implicate the quality and safety.

## 2. Herbal teas or tisane: Which term is appropriate?

Herbal tea is primarily consumed in every part of the world as a traditional preparation to maintain general health or alleviate specific morbidity. It is prepared from the aqueous extraction of different parts of various plants (either leaves, stem, flower, fruit, seed, root, bark, or mixture), excluding the tea leaves of *Camellia sinensis*. This botanical beverage is appropriately called tisane to avoid a mix-up with the actual tea, which is usually prepared by steeping (infusion) and boiling (decoction) or combination (Chandrasekara and Shahidi, 2018). They have gained growing interest among scientists and consumers due to their therapeutic and pleasant sensorial properties due to a broad spectrum of phytochemical

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substances that display myriads of bioactivities (Herrera *et al.,* 2018). The phytochemical profile of herbal tea variation depends on the species, agronomic aspects, manufacturing parameters, and domestic brewing techniques (infusion or decoction). It is perpetuated as a potential health tonic or dietary supplement in improving healthy aging (Alferink *et al.,* 2017; Shen *et al.,* 2020). From economic standpoints, herbal tea saw progressive growth by 8 percent in 2011, with growing market demand for herbal and fruit teas (Mansur, 2019). Tongkat Ali (*Eurycoma longifolia*), Gotu kola/Pengaga (*Centella asiatica*), Sabah Snake grass/Belalai Gajah (*Clinacanthus nutans*), Cat's whisker/Misai Kucing (*Orthosiphon stamineus*), Kacip Fatimah (*Labisia pothoina*), Noni /Mengkudu (*Morinda citrifolia*) are among the herbs popular in Malaysia used as a part of this traditional preparation. Leaves are the most used plant part from these popular Malaysian herbs groups, having relatively higher polyphenol content and proportionally higher in antioxidant activities than any part due to the greater exposure to UV-radiation-caused cell oxidative damage (Ribaudo *et al.,* 2019). European herbs such as German chamomile (*Matricaria chamomilla*) for insomnia and diabetic control, spearmint (*Mentha spicata*) for osteoarthritic stiffness and hormone control, rosehip (*Rosa rugosa*) for minor menstruation pain, and lemon balm (*Melissa officinalis*) for oxidative stress are made into tisane for daily diet supplement (1-3 cups) to enhance body's well-being (Etheridge and Derbyshire, 2019). Oxidative stress significantly impacts many chronic co-morbidities, such as diabetes, cardiovascular diseases, cancer, and premature aging. Dietary antioxidants sourced from the botanical diet include herbal infusions, have been evaluated, but their antioxidant mechanisms need further studies (Li *et al.,* 2014) and can be valuable tools to predict their activity against its therapeutic effect (Magcwebeba *et al.,* 2016).

The gaining popularity of herbal infusion is due to beneficial health effects and sensory characteristics, especially for antioxidant function and color. However, the color parameters of herbal infusion and their antioxidant property values were more inconstant than the green teas (Jin *et al.,* 2016). Thus, it is impossible to justify the correlation between these two qualities. In general, the researcher found that most herbal infusions have lower antioxidant property values than green teas. Only a few herbal infusions could be equivalent or exceptional to green teas, such as Rattan tea (*Ampelopsis grossedentata*) and Chinese rose tea (*Rosa chinensis* Jacq.) A popular alternative to typical tea in South Africa is the Cape herbal infusion which is comprised of 15 herbal species are classified into five categories: (1) leisure beverages (desirable aroma or flavor); (2) bitter tonic; (3) flatus-relieving; (4) stimulant or sedative; and (5) medicinal therapy (Van Wyk and Gorelik, 2017). Table 1 shows some scientific research on several herbal infusions with several therapeutic features, with most of them are air-dried and rarely followed the standard tea processing. Only a handful of researches showed the comparisons of processing techniques on herbal tea quality. More research is needed to study the influence of standard tea processing on herbal tea quality to acquire further knowledge on the dietary antioxidant potential.

A variety of botanical sources has been applied as the ingredient in the herbal infusion, including coffee by-products such as coffee-blossom tea, coffee-leaves tea, coffee-husks tea, and silver skin (Klingel *et al.,* 2020). Among the agricultural by-products that gain attention are the leaves. Two different tea processing methods, namely the Japanese-green-tea process (JGT) and black-tea-process (BTP), along with the age of coffee leaves (young and mature), have been employed, and the initial method results in higher antioxidant and anti-inflammatory activities (Chen *et al.,* 2019). Fermented grape by-products like skins and seeds have been applied in herbal infusion and serves as an imperative medium for supplementing dietary polyphenol – antioxidants (Vilela and Pinto, 2019). However, despite potential therapeutic benefits in male papaya flower herbal infusion, its sensory scores were perceived lower than the commercial teas (Bergonio and Perez, 2016). This poor sensorial acceptability may dampen purchase intention and decrease its marketability.

The antioxidant status of herbal infusion may vary due to the variety of herbal blends in the composition, manufacturing form (course, fine powder, or granule), and processing method. Three factors should be considered in evaluating the herbal infusions: 1) characterization of bioactive substances which may affect the antioxidant/oxidant capacity of tea types; 2) comparison of antioxidant/oxidant capacity values among the similar study; 3) appropriate sample size before making general conclusion (Ağagündüz, 2020).

*2.1 Tea enrichment: Pharmacological effects in herbal tea mixtures*

Turkish monoherbal tisane from *Melissa officinallis, Sideritis libanotica subsp. linearis* and *Stachys thirkei* showed that they could be dietary polyphenol sources and possessed potent antioxidant properties (Ertas and Yener, 2020). Since most herbal beverages are prepared from a single ingredient, some are blended in polyherbal mixtures to improve their palatability, like bush tea with rooibos and honeybush tea (Malongane *et al.,* 2020). However, some are blended to promote pharmacological effects enhancement or synergism. For example, a

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Table 1. Variety of herbal infusion, either monoherbal or polyherbal, derived from several types of processing and featuring some therapeutic properties

| Herbal infusion/ tisane | Type of processing | Therapeutic features | Reference |
|---|---|---|---|
| Bergamot leaves(*Citrus bergamia*) | Fresh | Anti-inflammatory | Baron *et al.* (2021) |
| Rooibos leaves tea | Air-dried | Neuroprotective effect | Pyrzanowska *et al.* (2021) |
| Mempening leaves (*Lithocarpus bancanus*) | Air-dried | Anti-diabetic | Almurdani *et al.* (2020) |
| Wild bitter Melon leaves (*Momordica charantia* Linn., Cucurbitaceae), and brimstone tree leaves (*Morinda lucida* Benth, Rubiaceae) | Air-dried | A-amylase and α-glucosidase inhibitory activities | Chokki *et al.,* (2020) |
| Asian Agrimony Tea (*Agrimonia asiatica* Juz., Rosaceae) | Air-dried | α-glucosidase inhibitor (anti-diabetic) | Kashchenko and Olennikov (2020) |
| Common fig leaves (*Ficus carica*) | Air-dried | Hypoglycaemic effect | Gillani *et al.* (2018) |
| Acorn leaves (*Quercus liaotungensis*) | Fresh | Inhibitory Activity against α-glucosidase and Protein Tyrosine Phosphatase 1B | Xu, Wang, Yue *et al.* (2018) |
| *Adesmia boronioides* and *Solidago chilensis* | Air-dried | Anti-proliferative activity (anticancer) | Gastaldi *et al.,* (2018) |
| Coffee leaves/walnut leaves | Air-dried | Dietary antioxidant | Colomban *et al.* (2017) |
| Bush sedum (*Sedum dendroideum*) tea | Fresh | Antioxidant and gastric health-promoting effects | da Luz *et al.,* (2019) |
| Billberry leaves (*Vaccinium myrtillus*) | Dried | α-glucosidase inhibitor (anti-diabetic) | Bljajić *et al.,* (2017) |
| Sweet potato leaves (*Ipomoea batatas*) | Green | Natural source of antioxidants, a potential to prevent non-communicable diseases | Mbouche *et al.* (2019) |
| Hungarian thyme (*Thymus pannonicus*) | Air-dried | Antioxidant, anti-bacterial | Arsenijević *et al.* (2016) |
| Common mugwort (*Artemisia vulgaris* L.) aerial parts | Fresh | Hepatoprotective effects and immunomodulatory properties | Corrêa-Ferreira *et al.* (2017) |
| Zedoary rhizome (*Curcuma zedoaria* Roscoe.) | Air-force oven-dried | Anti-hypercholesteraemic and anti-lipidemic | Tariq *et al.* (2016) |
| Cocoa (*Camellia ptilophylla*) leaves | Shade-dried | Anti-hyperlipidaemia and anti-obesity activities | Li, Yuan, Wang *et al.* (2017) |
| Beach wormwood (*Artemisia campestris* subsp. maritima) | Air-dried (leaves and roots) | Antioxidant, anti-diabetic (α-glucosidase inhibitor), anti-hyperpigmentation (tyrosine inhibitor) | Pereira *et al.,* (2018) |
| *Copaifera malmei* leaves | Air-dried | decreased intestinal inflammation by reducing macroscopical and microscopical colon injury | Pavan *et al.*, (2021) |
| Lavender (*Lavandula spica*) | Air-dried | Reduce depression and anxiety | Bazrafshan *et al.* (2020) |
| Soursop (*Annona Muricata* L) leaves | Fresh | Anti-diabetic (regulation on glucose absorption) | Yunivita *et al.* (2019) |
| Chicory leaves *(Cichorium intybus L.)* | Shade-dried | Modulate bone loss | Mohamed and Badr (2019) |
| Massoia *(Massoia aromatica Becc., Lauraceae)* bark | Dried bark | Immunomodulator in vitro | Hertiani *et al.* (2018) |
| Dolo magota (*Garcinia latissima*) fruit | Cabinet-dehydrated | Anti-cholesterol (HMG-CoA reductase inhibitor) | Monalissa *et al.* (2018) |
| Yareta or llareta (*Azorella compacta*) whole plant | Oven-dried (at 40° C) | immunomodulator in vitro | Tumová *et al.* (2017) |
| Asian Agrimony Tea (*Agrimonia asiatica* Juz., *Rosaceae*) | Air-dried | Anti-diabetic | Kashchenko and Olennikov (2020) |
| Hardy kiwi (*Actinidia arguta*) leaves | Air-dried | Anti-inflammatory | Kim *et al.* (2019) |
| Lime flowers (*Tiliae flos*), | Air-dried floral part | treatment of feverish colds and coughs | Melnyk *et al.* (2021) |
| Hairy rupturewort (*Herniaria hirsuta* L) | aerial parts | Anti-urolithiasis and anti-cholelithiasis | van Dooren *et al.* (2016) |
| *Cinnamomum porrectum* | Fresh and Blanched-dried | antioxidant, antimicrobial, and anti-inflammatory activities | Saetan *et al.* (2016) |

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Table 1 (Cont.). Variety of herbal infusion, either monoherbal or polyherbal, derived from several types of processing and featuring some therapeutic properties

| Herbal infusion/ tisane | Type of processing | Therapeutic features | Reference |
|---|---|---|---|
| Betel leaves (*Piper bettle* L.) | Fresh | Anti-fungal | Sartini *et al.* (2020) |
| Coltsfoot leaves (*Tussilago farfara* L.) | Air-dried | Anti-viral (source of essential amino acids) | Chromchenkova *et al.* (2020) |
| *Laurus nobilis* leaves | Air-dried | Improve blood lipid profile (Cardioprotective) | Chbili *et al.* (2020) |
| *Antirhea borbonica* leaves | Air-dried | Antioxidant and anti-inflammatory | Veeren *et al.* (2020) |
| Tamarind (*Tamarindus indica*), Dedalu (*Scurrula sp*), and Puteri Malu (*Mimosa pudica*) | Fresh and air-dried | Anti-diabetic (α-amylase inhibitor | Devi. Sy *et al.* (2019) |
| Thai summer tea (*Aegle marmelos* (L.) Correa, *Stevia rebaudiana* (Bert.) Bertoni, *Pandanus amaryllifolius* Roxb. and *Morus alba* L.) | Oven-dried at 45–50°C | Antioxidant | Tipduangta *et al.* (2019) |
| 'Beluntas' (*Pluchea indica*), Turmeric (*Curcuma longa*) and Their Mixtures | Air-dried | Anti-microbial and antioxidant | Zabidi *et al.* (2020) |

polyherbal tisane composed of Bay laurel (*Laurus nobilis*) leaves and Walnut (*Juglans regia*) leaves at equal amounts possessed high bioactivity compared to individuals (Finimundy *et al.,* 2020). However, additive or unwanted antagonistic effects may arise from these mixtures (Pyrzynska and Sentkowska, 2019). Thus, there is a need to study the possible herb-drug interactions carefully. A few teas or herbal enrichment efforts have been documented to share the polyherbal mixture benefits and drawbacks (Table 2). A few herbal enrichment efforts have been documented to share the polyherbal mixture benefits and drawbacks of the polyphenol contents/antioxidant activities (Table 2). Even though the listed research mostly showed beneficial impacts due to synergistic herbal blending, a considerable study on pharmacodynamics and pharmacokinetics must be done to eliminate the risk of antagonistic effects. Meanwhile, the use of sweeteners also shall be considered, which may have additive effects on the retention of phenolic compounds and their antioxidant activity, particularly stevia and steviol glycosides (Celaya *et al.,* 2021). Moreover, Zayapor *et al.* (2021) found that the pharmacological effects were influenced by sugar concentration and the type of sweeteners used, i.e., refined white sugar or unrefined brown sugars.

Additionally, tea enriched with spices is popular in Northern Indian, such as *Kahwa*, a traditional mixture of green tea extract and other spices such as saffron, cardamom, or occasionally supplemented with pepper or cinnamon and almond pieces. It was found that this tea has high antioxidant activity (DPPH at 40.68% inhibition) (Dhanjal *et al.,* 2020), which could be contributed by these spices chemical compositions (qualitatively and quantitatively) of monoterpenes and sesquiterpenes, which are responsible for flavor as well (Hajdari *et al.,* 2020).

## 3. Tea processing steps

Different types of teas are produced due to the processing methods with either the inclusion or exclusion of any processing step, type of leaves used (2 - 3 small leaves and tender buds or large and thick leaves of aerial tree parts), cultivation region, or mixed with other herbs/spices as well as scented with selected herbs (Zhang *et al*., 2020). The tea processing steps involved plucking, withering/wilting, bruising, oxidation/fermentation, "kill-green"/fixing, sweltering/yellowing, rolling/shaping, drying, aging/curing, and lastly, sorting (Figure 1). In addition, some manufacturers employed a traditional technique known as crush, tear and curl, CTC) in their processing, complementing the steps mentioned earlier (Li *et al*., 2021). These processing steps derived the tea variants such as green, white, yellow, and the widely consumed black tea. In comparison, green, white, and black tea have greater antioxidant capacity than fresh orange and apple juice and serve significant sources of dietary phenolic antioxidants (Shannon *et al.,* 2017).

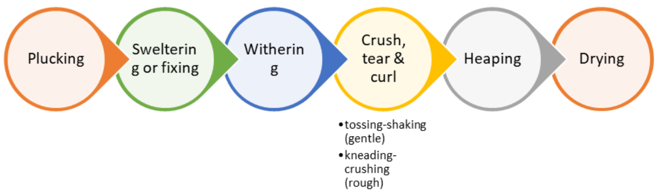


Figure 1. Common tea processing steps

At the initial stage, harvesting tea leaves is conducted with either hand plucking, mechanical, or shear harvesting, impacting the tea flavor, health benefits, and production economy. The hand plucking of

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Table 2. List of pharmacological effects in several mixed herbal infusions

| Herbs mixture | Pharmacological effect | References |
|---|---|---|
| *Moringa oleifera* leaves + ginger | Antagonistic effect in total phenolic content | Kumar *et al.* (2018) |
| *Moringa oleifera* leaves + tulsi, and *Moringa oleifera* leaves + lemongrass | additive effect | |
| Pu-erh tea + the pericarp of *Citrus reticulate chachi* | Synergistic effect on the activities of superoxide dismutase (SOD) and the activities of glutathione peroxidase (GSH-Px) | Zheng *et al.* (2020) |
| Stevia leaves + lemongrass, chamomile + tea leaves | Synergistic effect on ABTS antioxidant activity | Castañeda-Saucedo *et al.* (2020) |
| Spearmint leaves + black, red, and green teas | Synergistic effect on DPPH antioxidant activity | |
| Breadfruit leaves + cinnamon + clove | Additive effect on phenolic content | Lutfiani *et al.* (2020) |
| Bitter melon (*Momordica charantia* L) + red ginger (*Zingiber officinale* Roscoe) + curcuma (*Curcuma xanthorrhiza* Roxb) | Synergistic effect on DPPH antioxidant activity | Nasution and Syamira (2020) |
| Black berry *(Morus nigra*) + artichoke (*Cynara cardunculus*) + fig (*Ficus carica*) infusions | Synergistic hepatoprotective and antioxidant effect | Youssef *et al.* (2017) |
| *Thymus mastichina + Laurus nobilis + Juglan regia; Origanum vulgare + Chamaemelum nobile + L. nobilis + J. regia; Rosmarinus o cinalis + C. nobile + L. nobilis + J. regia*) | Synergistic effect on anti-tumor, anti-inflammatory, anti-fungal activity, anti-lipid peroxidation, and anti-bacterial | Finimundy *et al.* (2020) |
| *Larrea cuneifolia + Zuccagnia punctata + Larrea divaricata.* | Synergism on the antioxidant parameters (ABTS, FRAP, and 2-deoxy-D-ribose degradation assay) | Carabajal *et al.* (2020) |

two young leaves and their terminal bud are carried out at up to 4 plucking seasons (flush). The first flush (spring/Sencha) is between February to April, the second (summer) is between April to June, the third is the monsoon between June and October, and the autumn is between October and November in the Northern hemisphere. The later the flush stage is the more intense flavor and color of tea. However, the monsoon and autumn flush teas are considered lower quality and sold as a commercial tea bag or mixed with herbs and spice. Besides the plucking season factor that determines tea quality, the plucking interval also has a crucial factor, where the 7-day plucking round produced a better polyphenol profile than the 5-day but contained higher ash and fiber (Teshome, 2019). The mechanical and shear harvesting, on the other hand, are done at the aerial part of the tea tree, and the leaves' maturity is largely varied in bioactive composition and further impacted the flavor and antioxidant capacity (Kumar *et al*., 2018).

Leaves withering is conducted indoors (preferably in a controlled environment to avoid environmental factors fluctuations) or outdoors to reduce the moisture content by approximately 30% to 40 % and play an essential role in the quality of black tea (Ye *et al.,* 2019). The optimum withering duration is between 14 to 16-hour at a rate of 6 $kg/m^2$, at more than 30°C to achieve quality teas and allow desired flavor development (Tang *et al.,* 2018; Sharma and Dutta, 2018; Kalidass *et al.,* 2019). In a herbal tea study, the withering temperature at 90°C for 2 mins produces Ulam raja (*Cosmos caudatus*) that retains the highest bioactive components (Aprilia *et al.,* 2020). Withering duration can significantly influence amino acid content (especially theanine, a glutamic acid analog) and some essential and toxic mineral content (Al, Pb, and Ni) (Jabeen *et al.,* 2019). At this step, oxidation is started at a slow pace, where the longer withering duration, the more prolonged oxidation is and furthering the development of color and flavor of the tea.

However, the withering step is excluded in green and yellow tea processing but subjected to heat treatment or sweltering to depress the PPO or peroxidase enzymatic browning involved in oxidation. The oxidation defines the tea into categories: non-oxidized (green and yellow), moderately oxidized (oolong), totally oxidized (red/black), and prolonged oxidation (Pu'er/dark teas). The essential quality parameters in oxidation include exhaust temperature: 25°C - 27°C and humidity: 95% with concurrent air-flow to supply oxygen-rich air (Tharaga *et al.,* 2018). The duration of oxidation may depend on the desired quality of a final product. Sweltering, also known as fixing or kill-green step, is carried out by steam blanching, pan firing, or tumble heating (standard methods). The yellowing time influences the retention of bioactive components. Low blanching temperature and short blanching time were more beneficial to retain the active components, and the optimum blanching conditions were 120°C for 1 min (Lin *et al*., 2006). Commonly, the tea leaves are warmed up to 37°C for 6 - 8 hrs, with the optimum sweltering duration is 12 hours (An *et al.,* 2019). The depression of enzymatic browning during this stage significantly impacts the amino acids and polyphenol profiles that contribute to the sensorial

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and bioactivity qualities of the green and yellow teas (Guo *et al.,* 2021). Blanching maintained the chlorophylls and increased TPC and TFC due to the expanded pore size of dried leaves and increased yield extractability (Saetan *et al.,* 2016). A combination of steam blanching and oven drying of fresh litchi pericarps could retain the phenolic compounds and antioxidant capacity as a raw material (Kessy *et al.,* 2016). However, steam blanching significantly reduced the total phenolic and flavonoids content in *Moringa oleifera* leaves infusion (Wickramasinghe *et al.,* 2020) and contrarily increased the total carotenoid content (Nobosse *et al.,* 2017).

A unique difference between green and yellow tea production is "sealed yellowing" (Men-huang, 悶黃), involving a slow-oxidation process before drying. This step helps alleviate the grassy note character associated with green tea by resting the heated and dampened tea leaves for some time (Xu, Wang, Zhao *et al.,* 2018). The other oxidation process or bruising step intensifies the tea leaves' oxidation through kneading-crushing (heavy bruising) or tossing-shaking (light bruising). Some referred to this step as rolling and employing cutting, tearing, and curling, CTC technique. These actions induced polyphenol oxidase activity, which significantly influences the color and flavor of the tea. Most black tea in the market is produced by this method (Sarkar *et al.,* 2016).

Among the tea process unit operations, indoor withering, pan-firing, and drying steps impacted its catechin concentrations due to enzymatic oxidation, thermal degradation, and epimerization (Theppakorn, 2016). The epimerization of catechins was enhanced by the firing/roasting process in large-leaf yellow tea production, thus enhancing the levels of α-glucosidase inhibition and improves the hypoglycemic effect (Zhou *et al.,* 2018). In his latest research finding, Zhou *et al.* (2019) found that both yellowing and roasting are essential in acquiring a better polyphenol profile and desirable sensory properties. However, steaming and coarse kneading (intense rolling) are the essential parameters for the Japanese green tea manufacturing process (Qin *et al.,* 2018) to achieve those qualities, even though the latter step is similar to the CTC technique. Steam treatment was effective in reducing the undesirable vegetal aroma intensities in the *Cyclopia longifolia* infusion, and at the same time, increased sweet, fruity intensities (Alexander *et al.,* 2018). The traditional Sumatran coffee leaves herbal infusion, *kahwa daun,* involved three main processing techniques over low heat: pendiangan (traditional drying by a fireplace), smoking, and toasting, which differed from the typical tea processing techniques and other herbal infusions. The *kahwa daun* was slowly dried by the mentioned technique to a moisture content of 3.6 - 7.6% (wb) (Novita *et al*. 2018).

Modern methods such as microwave drying, freeze-drying, and superheated steam (SHS) have been shown to retain higher antioxidant and therapeutic properties than conventional oven drying (Jimenez-Garcia *et al.,* 2020). Freeze drying was cited as the drying technique that retained the highest polyphenol content and antioxidant property values (Rabeta and Lin, 2015; Feng *et al.,* 2018). However, oven drying retained higher antioxidant properties than SHS at 150°C and 175°C at the exact time (Roslan *et al.,* 2020). The author believed that the reduced polyphenol content is due to enzymatic and thermal degradation. Since the conventional drying showed a reasonable antioxidant retention at higher temperatures (> 150°C), less than 60 mins provides a more economically feasible option. After analysing the process advantages between the tea processing technique of green and yellow, the latter was found to offer more explorative potential due to higher antioxidant activity (DPPH scavenging potency and activity) than the green tea (Li, Chen, Zhu *et al.,* 2017), anti-hyperlipidemia (Teng *et al.,* 2018) the presumptive unique polyphenol profile without grassy-note flavor. Moreover, the yellow tea showed a strong inhibitory effect against the serum pro-inflammatory cytokines interleukin (IL)-6 and tumor necrosis factor (TNF)-α, and against gastric injury (Wang *et al.,* 2013).

### *3.1 Herbal tea drying*

Traditionally, drying of botanical parts used as an infusion is carried out either shade-drying, air-drying, or solar-drying as it is the most feasible way to achieve. Convection oven drying is later introduced to achieve consistent drying but negatively affects the phytochemical composition and color. Table 3 listed some of the favorable drying parameters used to evaluate the drying effect of herbal tea, whereby different profiles of polyphenol were obtained from different drying techniques (Pariyani *et al.,* 2017). In general, low temperature and shorter drying duration are encouraged to avoid detrimental effects on the herbal tea quality but are sufficient to reduce its moisture content to less than 8%. Free freeze-drying has shown the best drying technique in retaining the herbal tea quality among the techniques studied but has an economic drawback on the production scale. For future study, optimum operational control combined with programmed drying strategies should be emphasized for effective dehydration but feasible in energy and capital expenditure.

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## 4. Advantages and disadvantages of herbal infusions

Herbal products consumed are varied by cultures, geographical availability, and therapeutic purposes. The phytochemical composition of those herbs, especially polyphenol, shall be paid special attention to select a proper extraction method and the solvent used to obtain its optimum quality and meet the consumers' safety requirements. Water is the most practical and non-toxic solvent ready for consumption (Bhebhe *et al.,* 2015). In comparison with traditional water extractions, hot water infusion was an effective method for polyphenol extraction (Cittan *et al*., 2018). It may provide higher antioxidant values over decoctions (Fotakis *et al*., 2016), but to a lesser extent than the modern microwave-assisted extraction (MAE) (Petkova *et al*., 2017). However, MAE has its drawback due to the possibility of contaminant trace elements (Kilic and Soylak, 2020). Modern-day water extraction, such as hydrothermal extraction, is applicable for the isolation of polyphenols (Machmudah *et al.,* 2016; Apea-Bah *et al.,* 2020) but tends to retain more saponin than any other phytochemical (Ojiako *et al.,* 2018).

## 5. Botanical bioactive components: plant physiological factor

A few studies have shown that the phytochemical composition of an herbal infusion is heavily impacted by the botanical part used, type of harvesting (hand-picked or mechanical), and maturity stage. Sea fennel (*Crithmum maritimum*) infusion prepared from leaves was rich in phenolic compounds, especially Chlorogenic acid, compared to stem and flower (Pereira *et al.,* 2017). While, honeybush (*Cyclopia maculate*) stems infusion contained significantly higher hesperidin levels than the leaves (du Preez *et al.,* 2016). The leaves of cat's claw (*Uncaria tomentosa* L.) are also reserved as the more affluent plant part in proanthocyanidins and polyphenol than its bark (Navarro-Hoyos *et al.,* 2018). The age of the leaf dramatically influences the level of phenolic and flavonoids and relatively their antioxidant properties. The level of phenolic and flavonoids in mature leaves of *Aquilaria beccariana* are higher than the young and old leaves, and their levels are almost equal (Anwar *et al.,* 2017).

Moreover, *Cosmos caudatus* infusion prepared from old leaves showed decreased antioxidant activity but significantly had higher mineral content than mature and young leaves (Fatanah *et al.,* 2016). In another study, the yellow-fallen breadfruit (*Artocarpus altilis*) leaves flaunted the best anti-cholesterol activity correlated with its flavonoid content compared to the fresh green leaves (Riasari *et al.,* 2018). The petioles were also identified as a significant antioxidant activity source characterized by the highest polyphenol content found in the petioles and leaves of Sweet cherry (*Prunus avium*) cultivars Burlat and Regina (Dziadek *et al.,* 2018). Leaves harvesting by mechanical means was found to provide additional value in polyphenolic content than the traditional-derived method, particularly for chlorogenic acid but does not significantly differentiate consumers' sensory preferences (Coelho *et al.,* 2016).

Light is one of the most important environmental factors influencing herb quality, including phytonutrient content and effects on growth and development. The recent development and adoption of light-emitting diodes provide opportunities for targeted regulation of growth and phytonutrient accumulation by herbs to optimize productivity and quality under controlled environments. Red, blue, and ultraviolet (UV) light enhanced the concentration of essential oils and phenolic compounds in various herbs and improved antioxidant capacities of herbs compared with white light or sunlight, yet these improvement effects varied among species, compounds, and light treatments (Dou *et al.,* 2017).

The bioactive compound content can be manipulated by light irradiation to respond to a specific wavelength and intensity of light. When Red Raspberry (*Rubus idaeus*) is exposed to blue LED light, its leaves increase the content of Flavan-3-ols and the number of total polyphenols overall (Kobori *et al.,* 2019). While the antioxidant activity and the polyphenol content in wheat sprouts (*Triticum aestivum* L.) were enhanced when illuminated with blue LED light and sunlight, respectively (Raiciu *et al.,* 2020). Supplementation of blue (430 and 460 nm) and UV-A lights (380 and 400 nm) to Pak choi (*Brassica rapa* subsp. *chinensis*) before harvest also showed remarkably higher contents of total phenolics and flavonoids (Mao *et al*., 2021). However, Benincasa *et al.* (2020) reported that the effect of light was species-specific and generally not significant for sprouts. Light irradiation exposure under a particular wavelength and intensity is not only manipulated during the pre-harvest stage. Some researchers extend the application to manipulate the content of polyphenol and their antioxidant properties at the post-harvest stage in fresh products, like cabbage (Lee *et al.,* 2014), tomato (Castagna *et al.,* 2014), and Tatar buckwheat sprout (Ghimeray *et al.,* 2014).

## 6. Botanical bioactive components: post-production qualities – storage and steeping factors

Efforts in retaining the therapeutic-derived compounds have been introduced to ensure the consumer obtains its optimum benefit. However, botanical ingredients for infusion are susceptible to quality changes upon distribution and storage of the product, especially the light exposure. The UV irradiation decreases the antioxidative properties of *Echinaceae purpureae* dried florets if the herb is irradiated longer than 10 mins (Ramos and Pilawa, 2015). The light irradiation influence on the botanical product at the post-harvest stage depends on the light components and the solvent used. For example, oleuropein, a bioactive compound from *Olea europaea* leaves, decomposes faster under UV-C light in water than in ethanol (Longo *et al.,* 2017). Storing plant infusion for more than three months at a high temperature (50°C) showed a 50% loss in the total antioxidant activity and color fading (Jiménez -Zamora *et al.,* 2016). Therefore, it is advisable to store the dried herbs for infusion in a UV-light protected container at a temperature lower than ambient.

Brewing or steeping factors, including the plant part, temperature, time, and the ratio of the herb: water (HW), play significant influences in bioactive compound extractions. In general, total polyphenol content increased with a longer steep time, and hot-water extraction is preferable in achieving the best infusion with high antioxidant activities (Erkekoglou *et al.,* 2017). An optimum level of antioxidant and therapeutic properties of *Acantholippia deserticola* infusion was demonstrated at an HW ratio of 1:500 (w/v) for 5 mins at 100°C (Larrazabal *et al.*, 2018). Oven-dried breadfruit (*Artocarpus altilis*) leaf infused at 100°C, for 3 mins and HW ratio of 1: 100 (w/v) displayed the highest antioxidant and phytochemicals properties (Azli *et al.,* 2018). However, McAlpine and Ward (2016) found that the polyphenol contents were greatly influenced by the first 5 mins of brewing time but not their antioxidant capacity. However, consumers usually prepare infusions under suboptimal conditions, i.e., the duration of brewing, which is insufficient to extract the bioactive compound, thus incapable of showing substantial therapeutic effect (Sun *et al.,* 2017; Rocha *et al.,* 2020). Another brewing factor to be considered is the leaf condition: loose-leaf or ground powder and preparation pack type: loose-leaf, bagged, or powdered. An infusion prepared from ground herbs has high TPC and antioxidant activity even nearly multiplied compared to loose leaf (Kharobi and Soubh, 2019), which due to the water to the contact-surface area in powder is higher and facilitate an effective extraction. Nowadays, consumers prefer preparing herbal infusions from tea bags instead of loose-leaf for the sake of convenience. However, the evidence showed mixed findings that preparation-pack either in a bag or loose-leaf significantly influenced the polyphenol content and antioxidant activity. De Almeida *et al.* (2019) evidenced that tea bags showed higher antioxidant activity than loose-leaf samples under the same brewing conditions, but (Farooq and Sehgal, 2018) did not find it significantly different. Additionally, prolonging the brewing time does not increase antioxidant extraction capability (Cleverdon *et al.,* 2018).

## 7. Safety: natural phytochemical toxicity, heavy metal, and mycotoxin toxicity

Multiple studies showed the compelling therapeutic, and antioxidant effects of botanical sources used to prepare the herbal infusion and represent an essential source of dietary polyphenols and antioxidants to protect against biological oxidative stress. However, understudied herbal selection in the blending or preparation and over-dose consumption of herbal infusions may cause adverse health effects due to toxicity (Talib *et al.,* 2020). Herbal product manufacturers shall be responsible for producing standardized, evidence-proof safety and effective materials through robust preclinical and clinical studies before gaining approval for the products' health claims (Ahmad *et al.,* 2015). In herbal infusion, safety issues may be due to toxin contamination either derived from pre-harvest (pesticide residue and heavy metal exposure) or post-harvest periods (mycotoxin contamination) (Sedova *et al*., 2018). Another chance of herbal toxicity exposure is selecting the understudied plant material as the infusion ingredient or overdosage consumptions (Woo *et al*., 2012). Pharmacological knowledge is required for herbal tea producers to identify the potential herbal ingredient toxicity and the safe dosage before the product reaches the consumer.

### *7.1 Pesticide residues*

Pesticides are classified as organochlorine, organophosphate, carbamate, and pyrethroid, which are widely used to control agricultural pests for benefiting higher yields. It becomes a consumer safety concern when the residues are off the limit or accumulated in the body system. Common pesticide residue detected in herbal infusion includes biphenyl, chlorpyriphos, diethyltoluamide (DEET), terbuthylazine, piperonyl butoxide, pendimethalin, pirimiphos-methyl, tebuconazole, and dichlorodiphenyldichloroethylene (p,p'-DDE) (Beneta *et al.,* 2018). Organic farming is an approach to eliminate these pesticides from introducing into the infusion. The migration of pesticides into infusion is generally increased with increasing pesticide water-solubility, pesticide concentrations, and brewing conditions (high water temperature and longer duration) (Jiang *et al.*, 2020). The percentages of pesticide migration to infusions ranged from 6.74% for heptachlor to 86.6% for endrin in Polish tea, and herbal infusion samplings (Witczak *et al.,* 2018) raised a sense of particular awareness. However, the author detected

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levels of residual organochlorine pesticides (OCPs) found below MRLs' limit.

A list of studies on synergistic toxicity between pesticide and heavy metals in agricultural impact has been reviewed by Alengebawy *et al.* (2021), but their implications on human health are still under infancy studied to suggest a conclusion. Pesticides have different penetration abilities on the leaf surface and water solubility. Topical pesticide residues can be reduced by spraying water before harvesting the fresh leaves (Gao *et al.*, 2020). However, health concerns arise when the herbs are prematurely harvested before the absorbed pesticide is periodically degraded. Risk assessment for pesticide residue intake may help establish a realistic maximum residue limit (MRL) of pesticides in herbal infusion through a reliable, robust, and time-efficient detection technique (Hassaan and El Nemr, 2020).

Pyrethroids are the insecticides derived from the pyrethrum flowers (*Chrysanthemum coccineum* and *Chrysanthemum cinerariaefolium*). Since it is a botanical -derived compound, most people think it is safe, and providentially its migration rate is low (<6.70%), with its estimated values of the exposure risk being within the safe limit (Xiao *et al.*, 2017).

*7.2 Heavy metal contamination*

Botanical products are the main channel of heavy metals migration to the food system via agricultural soil. Accumulation and exceeding the permissible limits of aluminum, chromium, manganese, iron, cobalt, copper, zinc, cadmium, mercury, and lead are linked with health dysfunctions, and the herbal infusion can provide a valuable complementary source of these elements (Długaszek and Kaszczuk, 2020). Manganese and rubidium concentrations in the Austrian herbal infusion were lower than in the tea sample (Winkler *et al.,* 2020), and it was found that the elemental contents can be increased with the lemon addition (Gorgulu *et al., 2*016), where acidification showed higher ion concentrations, except for fluoride ions (Milovanovic *et al.,* 2018). Barium had the highest extractability, whereas chromium had the lowest extractability, and the level of polyphenol content correlated with the level of copper and manganese contents in the herbal infusions (Theuma and Attard, 2020). Interestingly, the migration rates for the concerned metals vary significantly between herbal infusion and tea, attributed to the level of tannin, which has metal-chelating properties (Schulzki *et al.,* 2017). Some herbs that have been identified as potent chelating agents used in heavy metals toxicity therapy include milk thistle (*Silybum marianum*), cilantro (*Coriandrum sativum*), ginkgo (*Ginkgo biloba*), turmeric (*Curcuma longa*), and green algae (*Chlorophyta*) (Mehrandish *et al.,* 2019).

Meanwhile, Ababneh (2017) reported that the estimated daily intake for the toxic elements of lead and cadmium via herbal infusions intake was distant from the World Health Organization (WHO) tolerable daily intake and still safe. Even though the estimative of exposure assessment for blood lead and inorganic arsenic showed that the current intake of herbal infusion is considered lower than the benchmark dose lower limit, children and pregnant women shall be cautious and limit the consumption to less than a single cup daily (Colapinto *et al.,* 2016; Milani *et al.,* 2018; Milani *et al.,* 2019).

*7.3 Phytochemical toxicity*

Botanical products are considered therapeutic and safe, but some are pharmaceutically identified and proven to be lethal for human consumption. Adverse reaction to primary organ dysfunction occurs when exposed to excessive dosage or antagonistic effects of combined bioactive compounds. Hepatotoxicity may be the most recurrent adverse reaction associated with herbal remedies causing liver dysfunctions such as transient liver enzyme abnormalities (Reddy *et al.,* 2016). It was found that approximately half of the commercial herbs and their blends contained at least one alkaloid. Pyrrolizidines were the most frequently present, where the phytochemical migration to homemade infusions may derive 45% pyrrolizidine (PA) and 6% steroidal alkaloids (Nardin *et al.,* 2018) require authoritative needs for routine controls. The occurrence and concentration of PAs in herbal products were correlated with the presence of PA-producing plants (Mulder *et al.,* 2015), i.e., Western herbs: borage leaf, comfrey and coltsfoot, and Chinese medicinal herbs: *Eupatorium cannabinum, E. japonicum,* and *Crotalaria assamica*. PA is terminally mutagenic, genotoxic, and carcinogenic, and herbal infusions were the typical contributors to the total exposure to PAs, up to 890 ng/kg BW per day (European Food Safety Authority (EFSA), 2016). However, based on Balanced Risk-Benefit Analysis (BRBA) data, PA contamination outweighs its benefits (Habs *et al.,* 2017).

Another type of alkaloid abundant in herbal infusions is tropane (TA) (Gañán *et al.,* 2020), in which atropine and scopolamine were the most frequently detected TAs. The migration rate for atropine and scopolamine to a standard-prepared herbal infusion was approximately 50% (Mulder *et al.,* 2016). It is naturally present in most Solanaceae family plant members, i.e., Jimsonweed (*Datura stramonium*), and has anticholinergic properties. The estimated daily acute dietary exposure to TA was an alarm warning to children and the elderly (Arcella and Altieri, 2018).

Aconite roots of Aconitum plants are widely used in Traditional Chinese Medicine (TCM), with myriads of therapeutic properties including anti-inflammatory, cardiotonic, analgesic, and anti-tumor. However, the herb intake can cause adverse effects in humans if taken from insufficient decoction time or exceeding the recommended dose, causing aconite poisonings (cardiotoxicity) like life-threatening bradycardia, ventricular arrhythmia, and hypotension (Sheth *et al.,* 2015; Chou *et al.,* 2018; Bonanno *et al.,* 2020). Ongoing educational campaigns on pharmacology/medication intake should be instigated for botanical pharmaceutical/ nutraceutical use to avoid intoxications and effective dosage.

### 7.4 Mycotoxin contamination

Dried herbs can harbor fungal growth, which later causes health concern over mycotoxins occurrence. The reported occurrence in dried herbs was only 12%; however, the health threat assessment revealed an alarming health threat for HT-2 toxin by fusariums in the infusions (Caldeirão *et al.,* 2021). A study in Latvia found that 90% of tea samples were positive for mycotoxin contamination, where Enniatin B and deoxynivalenol (DON) were the most frequently detected mycotoxins. The migration rate of mycotoxins from dry herbs to infusion is 32–100% (Reinholds *et al.,* 2019). Even though the initial author quoted the HT-2 alarming exposure, aflatoxins (AF) and ochratoxin A still demonstrated a health risk, with the margin of exposure values being below 10,000. The occurrence of AF type B1 and G1 was more than 50% in camomile infusion, where the total AF concentration can reach more than 30 µg/kg of sample. However, AF was not detected in linseed, lime, and fennel tea (Tosun *et al.,* 2016). The migration rate was proved to depend on the polarity of mycotoxin and the pH of infusion for mycotoxin possessing an acidic group (Chalyy *et al.,* 2021).

## 8. Conclusion

The terminology for herbal tea, herbal infusion, and tisane is seldom interchange but shall not be confused with the standard tea. The initial term is widely labeled as a dried leaf (loosed or powdered) intended for infusion but not equivalent to standard tea. Therefore, the tea leaf of *Camellia sinensis* enriched with medicinal herbs shall be clearly labeled not only as its common name but also in percentage mixture and origin. Therefore, a few absolute terms with precise definitions must be set down to facilitate consumer identification and avoid confusion.

The blended tea, i.e., a polyherbal mixture of tea leaf of *Camellia sinensis* with medicinal herbs or without tea leaves, are widely traded in the market and without rigorous inspection from the authority, can increase the risk of product adulteration and consumer vulnerability to fraud. Authentication of the herbal origin and bioactive presence is viable and recommended for the enforcement work using reliable and fast detection tools such as spectroscopic fingerprinting technique - chemometric analysis.

Monoherbal tea produced using standard tea processing methods such as green or yellow-type on herbal tea is a promising alternative for dietary antioxidants. However, replication of the processing technique does not guarantee replicated health benefits as standard tea. Thus, extensive research on the pharmacological quality is granted to ensure the efficacy and fill in the discrepancy between the standard tea.

This review can conclude that herbal infusion may provide some therapeutic benefits due to extensive scientific evidence. However, two significant issues must be clarified before ambiguous health claims and therapeutic allegations are blatantly advertised. First, authentication of botanical origin and the representative percentage in the mixture involving polyherbal tea blending need to be established. Second, the efficacy level of responsible bioactive compounds should be established and set as a biochemical marker for quality control with a fast and reliable detection tool and method. Finally, an evidence-based safety dosage for chronic consumption is due until a clinical trial with a sufficient sample size is done to conclude the verdict.

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