*Review*

# Comparative Review of Cold Maceration and Decoction Methods in Shaping the Antihypertensive Efficacy of Egyptian *Hibiscus sabdariffa* L.

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**Abstract:** Hypertension remains a leading global health challenge, particularly in low- and middle-income countries where non-pharmacological interventions are increasingly sought. *Hibiscus sabdariffa* L., commonly known as roselle or sour tea, has gained attention for its antihypertensive properties, largely attributed to bioactive compounds such as anthocyanins, phenolic acids, and flavonoids. This review evaluates the influence of extraction methods. Cold maceration and hot decoction shape the phytochemical profile and antihypertensive efficacy of *H. sabdariffa* in distinct ways. Evidence from in vitro, in vivo, and clinical studies indicates that both extraction methods yield beneficial compounds. Hot aqueous extraction consistently enhances phenolic content and demonstrates superior blood pressure-lowering effects. Mechanisms include angiotensin-converting enzyme (ACE) inhibition, nitric oxide modulation, and vascular histology restoration. Cold extraction better preserves anthocyanins, which are strongly linked to antioxidant and cardioprotective outcomes, though the overall hypotensive impact is comparatively moderate. The findings suggest that hot extraction is preferable for therapeutic applications, while cold extraction may be suitable for functional beverages aimed at maximising anthocyanin content. Future research should optimise extraction conditions to balance phytochemical stability and pharmacological efficacy. Clinical trials are needed to validate dosage forms, long-term safety, and potential interactions with conventional antihypertensive drugs. This review evaluates how extraction methods shape the antihypertensive efficacy of Egyptian *H. sabdariffa*, guiding its integration into affordable cardiovascular care.

**Keywords:** phytochemistry; pharmacology; functional foods; bioactive compounds; therapeutic applications

## 1. Introduction

Hypertension is a major cause of worldwide morbidity and mortality. It is estimated to affect 1.13 billion people globally [1]. By 2025, the number of individuals suffering from hypertension is projected to reach 333 million in developed countries and almost twice this number, about 639 million, in developing countries [2]. In Egypt, the prevalence of hypertension among adults in the years 1991–1993 was 26.3% [3]. If this prevalence rate remains valid, then 15 million Egyptians, out of a population exceeding 80 million, are expected to be currently hypertensive [4]. The impact of hypertension, in terms of associated morbidity, organ damage, and mortality, is highest in developing countries [5]. Although pharmacological antihypertensives are numerous, there remains a strong need for non-pharmacological approaches in the prevention and control of hypertension, particularly in resource-limited settings [6].

Dietary interventions such as garlic, onion, Chinese herbal teas, black and green tea, and *H. sabdariffa*, otherwise known as sour tea, have demonstrated positive effects on blood pressure control [7–10]. The use of *H. sabdariffa* as an adjunct therapy in hypertension may be ideal for developing countries. It is relatively affordable, easy to cultivate, can be integrated into multi-cropping systems, and is consumed as food [11]. It has also been used for medicinal purposes in China, Iran, West Africa, and other regions of the world [12]. Sour tea contains carbohydrates, proteins, fatty acids, flavonoids, minerals, and vitamins. Studies have described its anticancer, antibacterial, antioxidant, nephroprotective, hepatoprotective, diuretic, anticholesterol, antidiabetic, and antihypertensive properties [11,12]. Thus, its use has gained popularity among patients with hypertension because of perceived benefits and minimal side effects.

The global view of hypertension prevalence across 182 countries shows that the burden varies widely, ranging from 13% to 41% [13]. Each year, about 7.6 million deaths occur because of high blood pressure, representing 13.5% of all deaths worldwide [14]. Approximately two-thirds of adults aged 30 to 79 years living with hypertension reside in low- and middle-income countries [15–17].

Roselle (*H. sabdariffa*) has been widely used as food, drink, and a medicinal herb for hypertension and hyperlipidemia due to its cardioprotective properties [18,19]. Its main constituents are organic acids, anthocyanins such as delphinidin-3-sambubioside, cyanidin-3-sambubioside, cyanidin-3,5-diglucoside, and delphinidin, together with polysaccharides and flavonoids [20]. The red calyx, the structure surrounding the petals, is the part primarily used, especially in teas [21]. Roselle calyces have been widely investigated in clinical studies [22].

In other regions, *H. sabdariffa* calyces and beverages derived from them are known as hibiscus tea, bissap, roselle, red sorrel, Sudan tea, sour tea, or karkade. The term karkade is most dominant in the western region. The health benefits of plant foods are not only due to their macro- or micronutrient content but also linked to the presence of phytochemicals [23]. In vitro studies have shown that *H. sabdariffa* possesses antioxidant properties [24–28]. Animal models demonstrate hypocholesterolemic [29,30] and antihypertensive activity [9,10,31–33]. Concentrated *H. sabdariffa* drinks have been found to lower blood pressure in hypertensive patients [34].

This review critically evaluates how two widely used aqueous extraction methods, cold maceration and hot decoction, influence the phytochemical composition and antihypertensive efficacy of *H. sabdariffa*. By comparing their distinct mechanistic outcomes and therapeutic relevance, this analysis offers consolidated insights that extend beyond existing literature and provides a clearer framework for future formulation strategies and clinical applications in hypertension management and cardiovascular care.

## 2. The Structure of *H. sabdariffa*

*H. sabdariffa* is a member of the *Malvaceae* family, cultivated widely in tropical and subtropical regions. The plant is characterised by its stalks, roots, leaves, flowers, calyces, and seeds, each part containing distinct phytochemical elements that underpin diverse medicinal properties [18,19].

### *2.1. Botanical Description and Cultivation Context*

*H. sabdariffa* grows as an annual shrub reaching 1.5–2.0 m in height, with red or green stems, deeply lobed leaves, and large yellow flowers with red centres. The plant flowers during late summer to early autumn, and calyces are harvested at full maturity when anthocyanin content peaks. It thrives in sandy loam soils under tropical climates with annual rainfall above 1500 mm [8,22,35,36].

Cultivation is widespread across Africa, Asia, the Middle East, and the Caribbean, with Egypt, Sudan, Nigeria, and India recognised as major producers. Agronomic factors such as soil fertility, irrigation, and temperature strongly influence yield and phytochemical composition, particularly anthocyanin and organic acid levels [37,38]. Figure 1 illustrates the morphological features of *H. sabdariffa*.

#### 2.1.1. Flowers and Calyces

Flowers of *H. sabdariffa* are rich in organic acids (citric, malic), anthocyanins, glycosides, flavonoids, and fibre [37,38]. Calyces, the fleshy red structures surrounding the petals, contain similar levels of organic acids and anthocyanins, but negligible levels of glycosides and flavonoids [21]. Anthocyanins, such as cyanidin-3-sambubioside and delphinidin-3-sambubioside, are considered the active ingredients responsible for hypocholesterolaemic, antihypertensive, and antioxidant activities [7].

#### 2.1.2. Leaves

Leaves contain flavonoids, tannins, and mucilage [12]. Decoctions are traditionally used as stomachic agents, emollients, and remedies for cough and high blood pressure [9]. Quercetin and luteolin are the dominant flavonoids, contributing to antioxidant and anti-inflammatory activity [24].

**Figure 1.** Morphological features of *H. sabdariffa*.

2.1.3. Roots and Stalks

These compounds contribute to diuretic and antimicrobial properties. Polysaccharides such as arabinans and galactans also provide prebiotic activity, supporting gut microbiota balance and indirectly influencing cardiovascular health [11,39].

2.1.4. Seeds

Seeds are a rich source of protein, fatty acids, and sterols. Linoleic acid and phytosterols are the main constituents, with emerging evidence of hypolipidaemic activity and nutritional value. Seed extracts are being investigated for functional food applications, particularly for regulating lipid metabolism [39].

Overall, these morphological parts illustrate the plant's versatility in food, beverage, and medicinal contexts. Distinct plant parts contain unique phytochemicals that underpin diverse pharmacological activities. Table 1 presents the morphological parts of *H. sabdariffa* and their phytochemical anchors.

**Table 1.** Morphological parts of *H. sabdariffa* and their phytochemical anchors.

| Main Phytochemicals (Plant Part) | Representative Compounds | Reported Pharmacological Relevance | References |
|---|---|---|---|
| Organic acids, anthocyanins, flavonoids, fibre (Flowers) | Citric acid, malic acid, cyanidin-3-sambubioside, delphinidin-3-sambubioside | Antioxidant activity, vascular tone, hypocholesterolaemic effect | [36–39] |
| Organic acids, anthocyanins (Calyces) | Citric acid, malic acid, cyanidin-3-sambubioside | Antihypertensive activity, antioxidant stability | [21,22,37] |
| Flavonoids, tannins, mucilage (Leaves) | Quercetin, luteolin, tannins | Gastrointestinal relief, emollient, traditional antihypertensive use | [12,24] |
| Polysaccharides, tannins (Roots and stalks) | Complex arabinans, galactans | Diuretic activity, antimicrobial properties | [40] |
| Proteins, fatty acids, sterols (Seeds) | Linoleic acid, phytosterols | Hypolipidaemic activity, nutritional value | [40] |

*2.2. Ethnobotanical Relevance*

*H. sabdariffa* is consumed globally under different names, such as hibiscus tea, bissap, roselle, red sorrel, Sudan tea, sour tea, or karkade. In Egypt, karkade is culturally significant, consumed both as a functional beverage and as a traditional remedy for hypertension [12]. Ethnobotanical surveys confirm its use for antibacterial, diuretic, hepatoprotective, and cardioprotective purposes, with calyx decoctions forming the basis of most preparations [39].

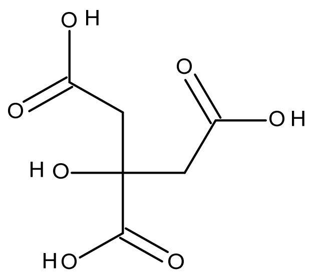
In West Africa, bissap is prepared as a festive drink and is central to social gatherings, while in Mexico and Central America, agua de jamaica is a staple beverage consumed daily. In the Caribbean, roselle is used both as a refreshing drink and as a medicinal infusion for blood pressure control. In Egypt, karkade is offered as a symbol of hospitality and cultural heritage, with both hot and cold preparations widely consumed. Globally, *H. sabdariffa* has become an important cash crop, supporting local economies through its integration into the beverage industry, nutraceutical markets, and traditional medicine systems [12,39].

## 3. Bioactive Constituents and Antihypertensive Mechanisms of *H. sabdariffa*

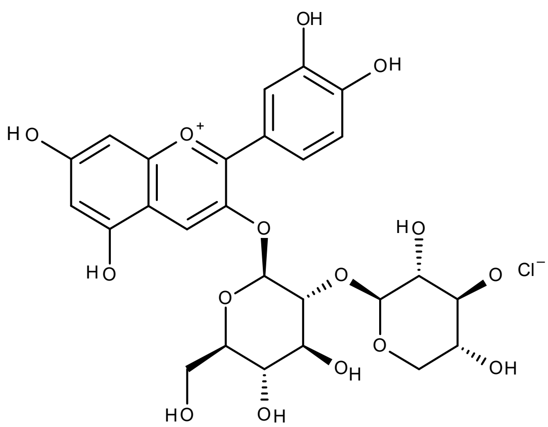
The structural diversity of *H. sabdariffa* underpins its pharmacological versatility. Flowers and calyces dominate in antihypertensive research due to their anthocyanin and organic acid content, while roots, leaves, and seeds contribute additional bioactivities. Understanding the distribution of phytochemicals across plant parts is essential for optimising extraction methods and tailoring *H. sabdariffa* preparations for therapeutic or functional use.

### *3.1. Bioactive Constituents*

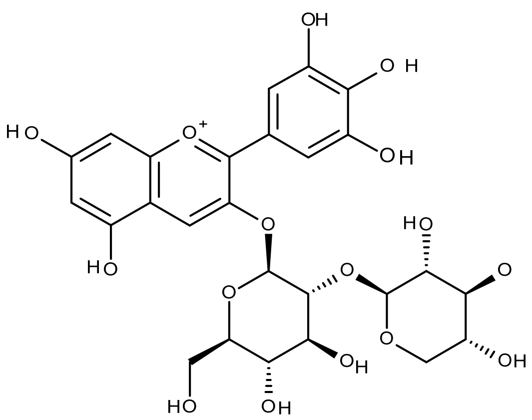
The main phytochemicals found in *H. sabdariffa* flowers are organic acids, largely malic and citric acids, anthocyanins, numerous glycosides and flavonoids, and fibre [36–38]. The calyces contain similar amounts of organic acid and anthocyanin, but negligible levels of glycosides and flavonoids [7]. Anthocyanins, mainly cyanidin-3-sambubioside and delphinidin-3-sambubioside, are believed to be the active ingredients responsible for hypocholesterolaemic, antihypertensive, and antioxidant activities [39]. Figure 2 highlights the main phytochemicals of *H. sabdariffa.*



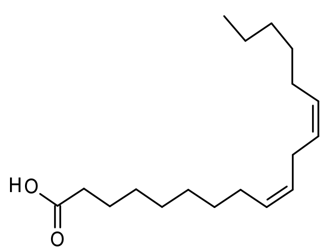
Citric acid



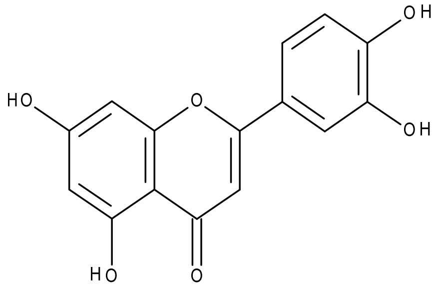
Cyanidin-3-sambubioside

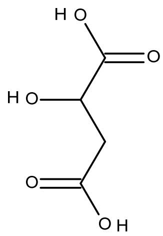


Delphinidin-3-sambubioside



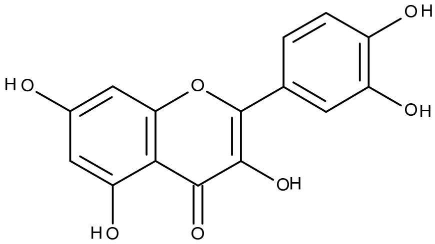
Linoleic acid





Malic acid

Luteolin



Quercetin

**Figure 2.** Bioactive constituents of *H. sabdariffa.*

*3.2. Phytochemical Variability*

Anthocyanin concentration in calyces varies significantly between African and Asian cultivars, with delphinidin-3-sambubioside predominating in African accessions, while cyanidin-3-sambubioside is more abundant in Asian cultivars. Environmental conditions such as soil fertility, rainfall, and temperature also influence phytochemical yield, while post-harvest handling and extraction methods determine the stability of anthocyanins and phenolic acids. These variations highlight the importance of cultivar selection and extraction optimisation when evaluating antihypertensive efficacy [38,39].

*3.3. Mechanistic Pathways*

Anthocyanins act as antioxidants, protecting endothelial cells and reducing oxidative stress. Organic acids contribute to vascular tone and flavour. Flavonoids modulate nitric oxide pathways, improving vascular relaxation. Polysaccharides provide prebiotic activity, supporting gut microbiota balance and indirectly influencing cardiovascular health [12,39]. Figure 3 illustrates the main mechanism of *H. sabdariffa*.

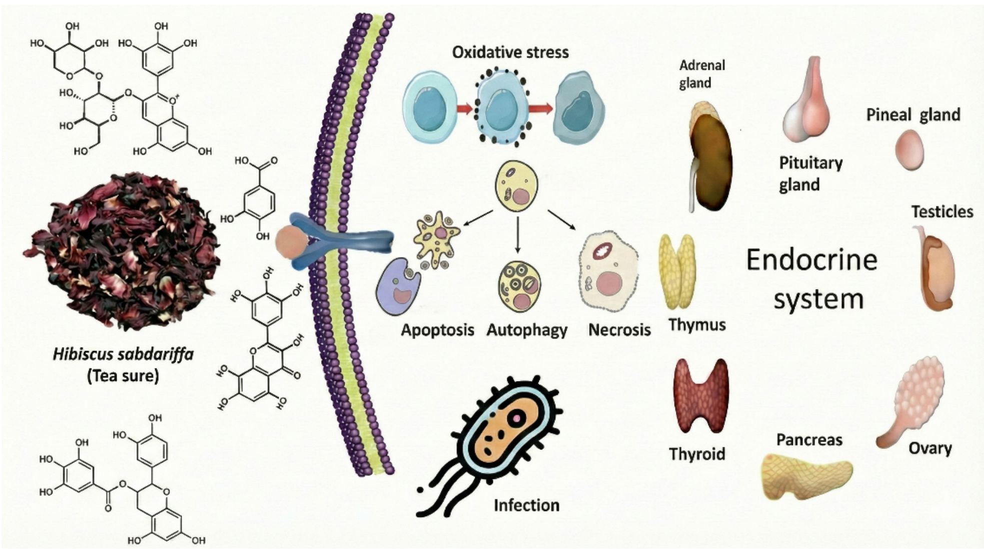



**Figure 3.** Overview of the main mechanism of *H. sabdariffa*.

## 4. Extraction of *H. sabdariffa*

Two principal aqueous methods are widely reported: cold maceration and hot decoction. Both approaches yield anthocyanins, phenolic acids, and flavonoids, but differ in efficiency, stability, and pharmacological outcomes [39,40].

Cold maceration preserves anthocyanins better, maintaining antioxidant potential and cardioprotective outcomes. However, its overall hypotensive effect is moderate compared to hot extraction [39]. Hot decoction enhances phenolic content and flavonoid yield, resulting in stronger ACE inhibition, nitric oxide modulation, and vascular histology restoration [39,41]. Solvent optimisation studies confirm that aqueous extracts outperform organic solvents in ACE inhibition, though prolonged heating may degrade anthocyanins [40].

Comparative extraction methods of *H. sabdariffa* and their antihypertensive outcomes. Extraction conditions shape phytochemical yield and mechanistic efficacy. Table 2 presents the comparative extraction methods of *H. sabdariffa* and their antihypertensive outcomes.

**Table 2.** Comparative extraction methods of *H. sabdariffa* and their antihypertensive outcomes.

| Extraction Method (Yield from 25 g Calyces) | Phytochemical Profile | Mechanistic Highlights | Reported Efficacy | References |
|---|---|---|---|---|
| Cold maceration (10.19%) | High anthocyanin stability, moderate phenolic acids | Antioxidant activity, endothelial protection | Moderate blood pressure reduction, strong antioxidant effect | [40,41] |
| Hot decoction (11.06%) | Enhanced phenolic acids, flavonoids, partial anthocyanin degradation | ACE inhibition, nitric oxide modulation, vascular histology restoration | Superior blood pressure reduction, improved vascular function | [40,41] |
| Solvent optimisation using UPLC MS/MS (Variable yield) | Mixed anthocyanins, phenolic acids depending on solvent polarity | ACE inhibition potential | Aqueous extracts most effective | [40] |

## 5. Mechanistic Implications of Extraction

Cold maceration produces extracts rich in intact anthocyanins, compounds strongly associated with antioxidant and cardioprotective activities. The preservation of cyanidin-3-sambubioside and delphinidin-3-sambubioside under cold conditions supports endothelial protection and reduces oxidative stress, explaining why macerated preparations demonstrate consistent antioxidant outcomes despite moderate blood pressure-lowering effects [41].

Hot decoction, in contrast, enhances the levels of phenolic acids and flavonoids, metabolites that drive angiotensin-converting enzyme inhibition and nitric oxide modulation, resulting in superior antihypertensive efficacy. Prolonged heating, however, can degrade anthocyanins and diminish antioxidant potential, highlighting the importance of optimised extraction conditions [40,41].

Comparative LC/MS profiling confirms that cold maceration maintains anthocyanin integrity, while hot decoction enriches phenolic content, differences that carry direct implications for dosage form development and clinical application [41].

While comparative studies between cold maceration and hot decoction provide valuable insights into the phytochemical and pharmacological profiles of *H. sabdariffa* extracts, certain limitations must be acknowledged. Variability in extraction conditions, such as temperature, duration, and solvent ratios, may influence compound stability and yield. Additionally, differences in dose ranges, experimental models, and cultivar sources across studies complicate direct comparisons and may affect reproducibility. These factors highlight the need for standardised protocols and controlled clinical trials to validate the therapeutic relevance of each extraction method.

## 6. Conclusions

In summary, *H. sabdariffa* exhibits significant antihypertensive potential in in vitro, in vivo, and clinical studies. Both cold maceration and hot decoction yield distinct phytochemical profiles that contribute to its antihypertensive effects. This review highlights a critical trade-off: hot decoction increases phenolic content and may be more suitable for therapeutic applications due to stronger angiotensin-converting enzyme inhibition, nitric oxide modulation, and restoration of vascular histology. In contrast, cold maceration preserves thermo-sensitive anthocyanins, which support antioxidant and cardioprotective outcomes. However, the overall blood pressure-lowering effect of cold maceration remains moderate, making it more appropriate for antioxidant-rich functional beverages.

Future research should prioritize optimizing extraction protocols to balance compound stability with pharmacological efficacy, as both phenolic and anthocyanin groups are essential for the cardiovascular effects of *H. sabdariffa*. Rigorous clinical validation through well-designed trials is required to establish precise dosage, long-term safety, and potential interactions with conventional antihypertensive medications. Additionally, translational studies are necessary to bridge laboratory findings with affordable and culturally appropriate formulations for integration into evidence-based cardiovascular care, particularly in resource-limited settings.

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