

Rooibos Tea and Health: A Systematic Review of the Evidence from the Last Two Decades

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Abstract

An expanse of research has investigated the effects of black and green teas in relation to aspects of health. Rooibos tea, also known as Red bush is derived from the South African Cape fynbos plant, *Aspalathus linearis*, and is caffeine free, naturally sweet and abundant in polyphenols. Evidence related to the health aspects of drinking Rooibos tea is advancing, but does not appear to have been collated. Therefore, we aimed to examine the health effects of Rooibos tea through a systematic review of the literature. A PUBMED search was undertaken (2000 up to June 2020) for human and laboratory studies investigating the efficacy of Rooibos in relation to health. Seven human studies and 49 laboratory studies were identified. Overall Rooibos tea consumption seems to benefit the lipid and redox profiles of those at risk of cardiovascular disease. It also appears to possess other promising 'general' effects on glycaemic control, bone, liver, cognitive and respiratory health. Ongoing research using standardised interventions is now needed to help formulate congruent conclusions that are relevant to public health.

Keywords: Rooibos tea; Poly phenols; Health; Evidence-base

Introduction

The pattern of health and disease is changing-continued shifts in longevity mean that multimorbidity and 'disease clusters' are now on the rise [1]. It is well appreciated that lifestyle e.g. alterations in diet, physical activity and avoiding smoking can improve outcomes for medical conditions such as cardiovascular disease [2]. There is already an extensive body of evidence showing that drinking two to three cups of tea daily could be beneficial for health, including reduced risk of cardiac death, coronary artery disease, stroke, type 2 diabetes mellitus and total mortality [3]. Beneficial inter-relationships have also been observed for several cancers, cognitive, skeletal and maternal health [3]. Most of this research has focused on green, black and oolong tea [4].

"Rooibos" is Afrikaans for "red bush" [5]. It is prepared from unfermented and fermented plant material from the Cape fynbos plant, *Aspalathus linearis* [6,7]. In South Africa, the proportion of black tea drinkers has declined between 2011 and 2015, from 58.6% to 51.5% whilst the percentage of Rooibos consumers has risen from 29.4% in 2011 to 30.9% in 2015.8 The demand for Rooibos tea is also extending further afield with South Africa exporting Rooibos tea to more than 30 countries [8].

Such shifts in consumption habits are being attributed to rising awareness and interest in the health properties of Rooibos tea [8].

The health properties of rooibos tea have been ascribed to it being caffeine free and its abundant phenolic composition [9,10]. Rooibos tea has a divergent polyphenol profile and is a rare dietary source of dihydrochalcones-aspalathin and nothofagin which possess potent antioxidant actions [11-13]. Aspalathin and nothofagin are the main flavonoids in Rooibos tea and have a particularly strong anti-oxidative activity, though aspalathin tends to be lower in fermented than unfermented foods [10,12,14]. This is relevant to health as the antioxidants present in rooibos may help to protect against oxidative stress which is known to induce inflammation and other health conditions [10,15].

Rooibos tea is naturally slightly sweet with caramel, floral, honey and woody undertones [16]. It has been used both as a tisane, as well as consumed traditionally for medicinal purposes and has been popular in South Africa for generations [5,11]. Traditionally, rooibos has been used for its medicinal properties in South Africa to help alleviate allergies, asthma, dermatological conditions and infantile colic [17]. Both the leaves and fine stems can be used as herbal tea, predominantly in the traditional 'fermented' (oxidised/aerated) red-brown form but also in its 'unfermented' (unoxidized/aerated) green form [18]. Rooibos tea can also be extracted and dried, spray-dried/freeze-dried to form powdered rooibos tea extract (RTE) which is also abundant in polyphenols [5]. Traditionally fermented beverages such as Kombucha have been produced effectively using rooibos leaves [19].

Increasingly, rooibos has been studied in human populations, mainly for its antioxidant and cardio protective properties [14,20,21]. Alongside this, over the years a growing body of laboratory and mechanistic studies have investigated how rooibos tea could impact on health. Given the gaining popularity of rooibos tea, the current publication collates evidence from human and laboratory studies, published over the last two decades. Such a review does not appear to have been undertaken previously. The present review focuses on rooibos tea which has been gaining popularity both in its native province the Western Cape of South Africa and worldwide in recent years [8].

Methods

The National Centre for Biotechnology Information (NCBI) search engine (PubMed) was used to extract relevant publications. Two search phases were undertaken. In Phase 1 English-language human studies published between January 2000 (month start) and June 2020 (month start) were screened. Publications were included if they used Rooibos tea or RTE and studied a named health outcome. Studies were excluded if they were conducted with children due to potential ethical issues, focused on chemical profiling, used a multi-intervention or did not specify a distinctive health outcome. External health conditions such as skin healing were also excluded.

The search terms “Rooibos”, “Red bush” or “*Aspalathus linearis*” were used. ED and TB identified the scientific publications. In Phase 1 the database search was restricted to human studies. In Phase 2 the search was restricted to laboratory studies the same search terms were applied. Data extracted from each human study included: (1) Study (author, year, location and reference number), (2) Subjects (age, gender, number), (3) Study design (type), (4) Tea intervention (type) (5) Intervention type (dosage) and (6) Main findings. Data extracted from each laboratory/mechanistic study included: (1) Study (author, year and reference number), (2) Study Design, (3) Intervention (type), (4) Main outcome and (5) Main findings.

Results

In Phase 1 using the applied search terms 47 human studies were identified. Of these, three were review papers, three had methods that were unclear or not fully reported, five were laboratory studies and 29 irrelevant as they did not investigate health outcomes. Subsequently, after these exclusions seven human studies were included in the final review. Of the human studies three were conducted in South Africa [21-23], one in the USA [24], one in Italy [14], one in Sweden [25] and one in Germany [20].

In Phase 2 91 laboratory studies were first identified. Two of these were excluded due to them being multi-interventions, two focused on external (skin) conditions, four were review papers, seven had methods that were unclear or not fully reported and 27 were irrelevant as they did not measure health outcomes. This resulted in 49 laboratory studies being included in the main paper. The algorithm of qualifying papers is shown in figure 1.

Human Studies

Seven human studies were identified using Rooibos tea preparations (Table 1) [14,20-25]. Sample sizes ranged from eight to 40 subjects. Interventions also varied between studies. Most studies used Rooibos infusions that had been steeped for approximately 10 minutes in hot water infusions [20,23,25]. One study provided Rooibos tea (two 125 ml cups each made with two tea bags, low mineral content water and a brewing time of 5 min at 90°C) for 30 days [23]. Other research

provided six cups of fermented, traditional Rooibos daily (one tea bag in 200ml with an infusion time of 5 minutes) for 6 weeks [21].

Three studies reported positive findings in relation to aspects of health [21,22,25]. One study used *ex vivo* samples from atopic adults showing that extracts prepared from both fermented and unfermented Rooibos inhibited basophil activation, an effect that was stronger using the extract of fermented Rooibos [22]. These findings are aligned with that from earlier laboratory models [26] and indicate that Rooibos appears to possess anti-allergic effects by inhibiting antigen- and calcium ionophore-stimulated degranulation. One of the largest trials conducted on 40 participants observed significant increases in plasma total polyphenol levels, reductions in markers of lipid peroxidation, improvements in lipid profiles (low-density lipoprotein declined and high-density lipoprotein increased) and redox status [21]. Effects were observed after drinking six cups of fermented (traditional) Rooibos tea daily for 6 weeks [21]. Another trial looking into underpinning mechanisms showed that freshly prepared Rooibos tea (made with 10g tea in 400ml boiled water for 10min using a tea filter) significantly inhibited angiotensin-converting enzyme (ACE) activity, 30 and 60 minutes after ingestion, indicating possible cardiovascular effects *via* the inhibition of ACE activity [25].

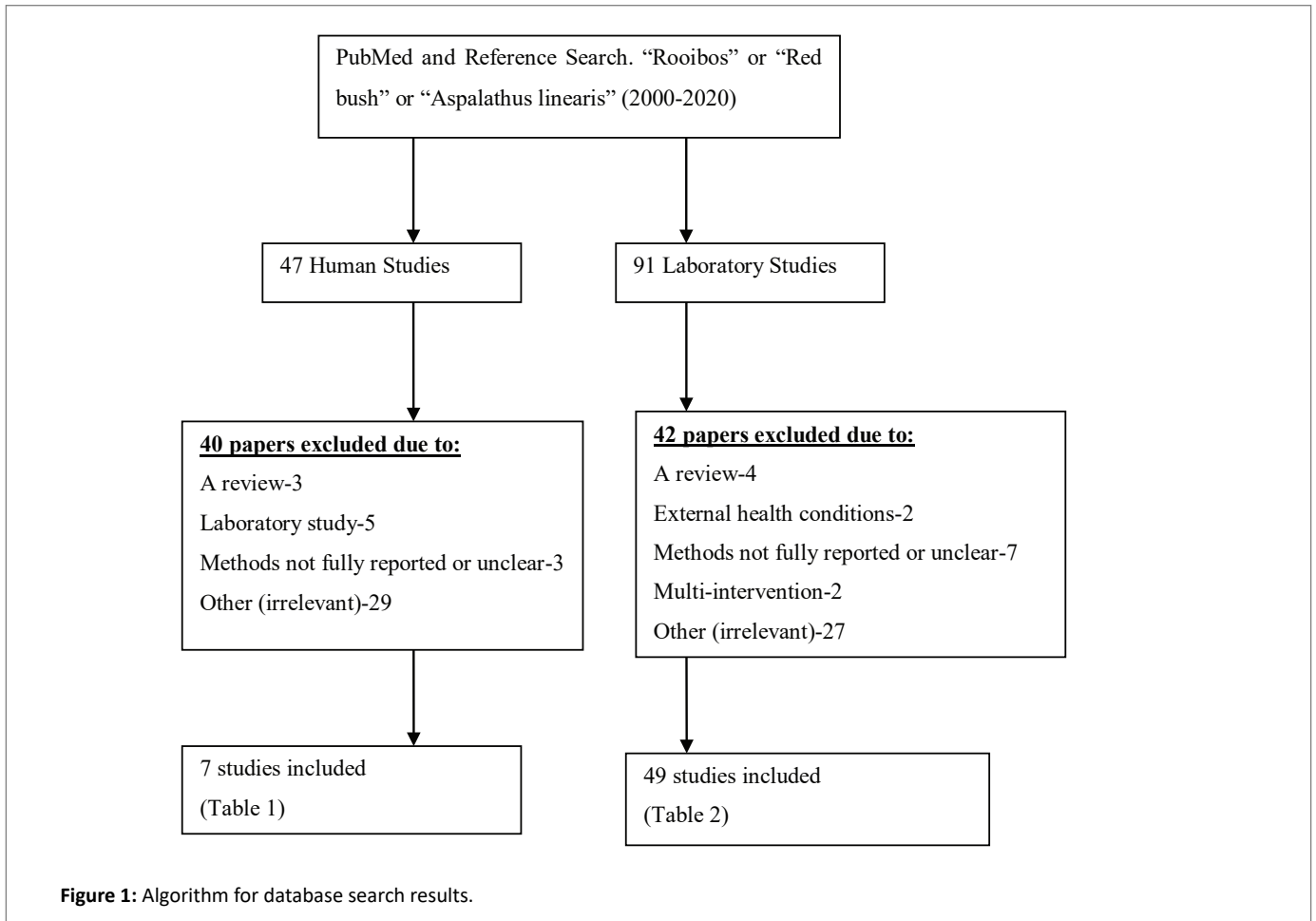
Two human studies focused on aspects of metabolite absorption and bioavailability [14,20]. In a human crossover study where 500 ml unfermented Rooibos tea was ingested aspalathin (a dihydrochalcone C-glucoside) was found to be particularly bioavailable [20]. An earlier bioavailability trial comprised of 10 adults drinking a similar quantity of Rooibos tea also showed that most metabolites were absorbed either *via* the small or large intestine [14]. In two trials involving Rooibos tea ingestion, one did not show any significant effects on renal stone formation [23] and the other showed that rooibos tea and plain water similarly rehydrated 23 athletes [24].

Laboratory Studies

A wealth of research has studied the health effects and potential mechanisms of Rooibos tea and its associated flavonoids. Forty-nine laboratory/mechanistic studies were identified and published over the last two decades. Of these, eleven focused on aspects of oxidative stress and antioxidant activity [10,12,27-35]. Four studies observed improvements in dimensions of sperm function [36-39]. This included enhanced sperm velocity, vitality, acrosome structure and membrane integrity [36-38]. These effects were attributed to high levels of antioxidants found in Rooibos, sequestering reactive oxygen species and lipid peroxidation [38,39].

Other research has focused on aspects of metabolic health. Some work has found associations between unfermented/green Rooibos extract and improvements in fasting blood glucose levels using type 2 diabetic mice [40]. Similarly, *In vitro* work showed that Rooibos extract high in aspalathin had a sustained glucose lowering effect [41]. Other work indicated that aspalathin or nothofagin flavonoids inhibit glucose-mediated vascular hyperpermeability and inflammation [42]. A further seven studies showed that Rooibos could improve insulin resistance and have antidiabetic potential [43-49].

With regard to potential mechanisms aspalathin found in Rooibos stimulated glucose uptake in muscle tissues and insulin secretion from pancreatic beta-cells in a type 2 diabetes mouse model [48]. Work by Ulicna O, et al. (2006) found that the antioxidant compounds in Rooibos tea prevented oxidative stress concluding that it could be a suitable adjunctive therapy for diabetic vascular conditions [49]. One study using a cell model found that a fermented Rooibos infusion prepared at ‘cup-of-tea’ strength and the soluble matter of the infusion



inhibited adipogenesis, also implying a potential role in obesity prevention [50]. These findings imply a potential role in glycaemic regulation.

Other research suggests beneficial effects on aspects of bone health [51,52], hepatoprotection [31,43,44,53], allergic response [26] and immune function [54,55]. Rooibos tea has been found to improve osteoblast activity [52] while fermented Rooibos was found to inhibit osteoclasts and associated gene expression [51]. Some work has discovered that Rooibos tea could help to stabilise the liver from injury [12]. In another study Rooibos extract eased induced liver injury by suppressing oxidative stress and the formation of pro-inflammatory cytokines [31]. A laboratory model showed that Rooibos tea acted as a 'hepatoprotector' showing histological regression of liver cirrhosis and steatosis in an experimental model of liver cirrhosis [53].

Alongside these findings, other evidence from laboratory models suggests inter-relationships between Rooibos ingestion and improvements in spatial memory, [56] reduced brain oedema and neuronal apoptosis, [57] reductions in esophageal papilloma size, [58] antispasmodic effects, [59,60] bronchodilation, [60] and chemoprotection [61,62].

Discussion

Overall there appears to be a growing body of evidence relating to Rooibos tea and various biological health outcomes. The largest body of evidence is currently derived from laboratory and mechanistic studies although human research is emerging. Research focusing on

cardiovascular health looks particularly promising. The trial conducted by Marnewick JL, et al. (2011) [21] was well conducted showing that drinking six cups of fermented, traditional rooibos daily significantly improved the lipid profile and redox status which is relevant to adults at risk for developing cardiovascular disease. Elsewhere other review findings also conclude that Rooibos appears to have preventative and complementary therapeutic benefits in the context of cardiovascular disease [63].

The antioxidant properties of Rooibos tea and its ability to sequester oxidative stress are also prominent in the research [27,34,49,64]. The polyphenols aspalathin (present at >5 mg/l) and nothofagin (present at <1 mg/L) found in Rooibos tea have been attributed to some of its health benefits [65,66]. Antioxidants such as these suppress oxidative stress in the body which has been implicated in the pathophysiology of certain diseases including Alzheimer's disease [67]. Several laboratory studies concentrated on aspects of sperm function [36-39]. Fermented Rooibos, in particular, was found to improve several dimensions including sperm concentration, viability and motility [38]. These findings imply that Rooibos consumption could have a role to play in supporting male fertility, namely by sequestering oxidative damage by improving antioxidant defence mechanisms and subsequently improving the sperm quality and function [39]. Human randomised controlled trials are now needed to explore this.

Fermented Rooibos extracts have been found to inhibit human basophil activation [22] a finding that supports earlier laboratory research showing that Rooibos has allergen-dependent inhibitory

Table 1: Rooibos Tea & Health: Evidence from Human Trials.

| Study (Author- Year- Location- Reference Number) | Subjects (age- gender- number) | Study design | Tea Intervention (type) | Tea Intervention (dosage) | Main findings (with any reported significant p-values) |
|--|--|--|--|--|---|
| Pedretti s- et al. (2020) [22] South Africa | n=9 atopic adults | Used ex vivo samples from atopic patients | Fermented and unfermented Rooibos extracts | Three optimised decreasing concentrations of unfermented (0.1- 0.03 or 0.01mg/ml) or fermented Rooibos extracts (0.05- 0.017 or 0.005mg/ml) were used during the experiments | Rooibos extracts inhibited basophil activation in a dose-dependent non-allergen specific manner. The inhibitory effect was stronger using fermented versus unfermented extract. |
| Rodgers A- et al. (2016) [23] South Africa | n=8 calcium oxalate (CaOx) renal stone formers | 30-day trial | Green tea from Japan or Rooibos from South Africa | Samples were prepared for analysis by adding 250 ml of boiling water to each teabag. These were removed after brewing times of 5 and 10 min. | Ingestion of Rooibos tea does not reduce the risk factors for CaOx stone formation in humans- |
| Breiter T- et al. (2011) [20] Germany | n=12 healthy males. | 24-hr crossover trial. | Different Rooibos drinks from unfermented Rooibos or a placebo | 10g Rooibos extracted with 500ml boiling water seeped from 10 minutes | On average a total of 0.76nmol of flavonoids were detected during their peak concentration after intake of the Rooibos tea- accounting for 0.26% compared to the total amount of flavonoids ingested. |
| Marnewick JL- et al. (2011) [21] South Africa | n=40 volunteers | 6-week trial | Fermented/ traditional Rooibos | Six 200 ml cups daily (one tea bag per cup; 5 minute infusion time). | Consumption of fermented- traditional Rooibos significantly improved the lipid profile as well as redox status- both relevant to heart disease- in adults at risk for developing cardiovascular disease. |
| Persson IA- et al. (2010) [25] Sweden | n=17 healthy volunteers. | Three phase randomized- three-phase- crossover study. | Green tea- black tea or Rooibos tea (South Africa) | 10g tea in 400ml 10 min infusion freshly prepared and cooled so the participants could drink it within approximately 2min. | Oral intake of a single dose of Rooibos tea significantly inhibited ACE activity after 30 min ($p < 0.01$) and after 60 min ($p < 0.05$). Rooibos tea may have cardiovascular effects through inhibition of ACE activity. |
| Utter AC- et al. (2010) [24] USA | n=23 athletes | Randomized- cross-over design with three different study arms. | Rooibos tea- carbohydrate beverage or bottled water (placebo) | NR (restricted access paper) | Rooibos tea was no more effective in promoting rehydration than plain water. |
| Stalmach A- et al. (2009) [14] Italy | n=10 volunteers | Bioavailability trial | Fermented or unfermented Rooibos tea | 500ml | The overall metabolite levels excreted were 82 and 352 nmol- accounting for 0.09 and 0.22% of the flavonoids in the fermented and unfermented drinks- respectively. Most of the aspalathin metabolites were excreted within 5 h of tea consumption- implying absorption in the small intestine. |

Key: ACE- Angiotensin-Converting Enzyme; NR- Not Reported.

Table 2: Rooibos Tea and Health: Evidence from Laboratory Studies.

| Study (Author-Year- Reference Number) | Laboratory/ Mechanistic study | Rooibos tea Intervention (type) | Main outcomes | Main findings |
|---------------------------------------|---|--|------------------------------------|--|
| Lawal AO- et al. (2019) [27] | <i>In vitro</i> antioxidant capacity | Aqueous extracts of fermented Rooibos- green Rooibos and Honey bush. | Oxidative stress | Herbal extracts offered protection against diesel exhaust particles that induced oxidative stress and inflammatory response. |
| Mazibuko-Mbejeet SE- al. (2019) [43] | <i>In vitro</i> - using liver cells | Aspalathin treatment | Hepatic insulin resistance | Aspalathin improved insulin signalling and mitochondrial bioenergetics. |
| Mazibuko-Mbeje SE- et al. (2019) [44] | <i>In vitro</i> - using rats | Aspalathin-enriched green Rooibos extract | Hepatic insulin resistance | Green Rooibos extract showed potential in ameliorating hepatic insulin resistance by improving insulin sensitivity <i>via</i> PI3K/AKT- FOXO1 and AMPK-mediated pathways. |
| Morishita Y- et al. (2019) [26] | Rat basophilic leukaemia cells | Quercetin- luteolin and chrysoeriol were mixed in the ratio that occurs in Rooibos tea extract | Allergic response | The mixture inhibited antigen- and calcium ionophore-stimulated degranulation to the same degree as whole Rooibos tea extract. Flavonoids underly the degranulation inhibitory activity of rooibos tea. |
| Orlando P- et al. (2019) [28] | Diabetic and non-diabetic vervet monkeys | 90 mg/kg of aspalathin-rich green Rooibos extract for 28 days. | Oxidative stress- LDL cholesterol | Green Rooibos extract could counteract hyperglycemia-oxidative stress and dyslipidemia- lowering cardiovascular risk factors linked to diabetes. |
| Pyrzanowska J- et al. (2019) [56] | Sprague-Dawley male rats | Infusions- prepared using 1- 2 and 4 g of 'fermented' Rooibos leaves for 100 ml of hot water. | Spatial memory | All treated rats showed improvement of long-term spatial memory. Striatal dopamine and 3-methoxytyramine levels were increased in treated rats. |
| Uličná O- et al. (2019) [12] | Rats with carbon tetrachloride-induced liver damage | Rooibos tea administration | Antioxidant activity- liver damage | Improved histological features support the view of antioxidant and membrane-stabilizing activity of Rooibos tea. This may play a role in the protection of the liver from injury caused by known toxins. |
| Dludla PV- et al. (2018) [45] | Diabetic mice | Aspalathin intervention | Glycaemic control | Metformin and a high dose (130 mg/kg) of aspalathin ameliorated diabetic symptoms i.e. abnormally raised fasting plasma glucose levels. |
| Moosa S- et al. (2018) [51] | Murine study | Rooibos tea extract | Bone health | Fermented Rooibos had a more potent inhibitory effect on osteoclasts and associated gene expression than unfermented Rooibos extract. |
| Yang S- et al. (2018) [71] | Murine study | Aspalathin and nothofagin from green Rooibos | Sepsis | Aspalathin and nothofagin appear to protect mice against sepsis-triggered renal injury. |
| Akinrinmade O- et al. (2017) [57] | Adult male Wistar rats | Fermented Rooibos herbal tea | Brain oedema- neuronal apoptosis | Long-term consumption of fermented Rooibos tea significantly reduced brain oedema and neuronal apoptosis. |
| Dludla PV- et al. (2017) [46] | Diabetic mice | Aspalathin intervention | Glycaemic control | Aspalathin maintained cellular homeostasis and protected the myocardium against hyperglycemia-induced oxidative stress by activating Nrf2 and its downstream target genes. |
| Johnson R- et al. (2017) [72] | <i>In vitro</i> | Aspalathin intervention | Cardioprotection | Aspalathin co-treatment could protect the myocardium from Dox-induced cardiotoxicity. |
| Johnson R- et al. (2017) [73] | Cardiomyocyte model | Aspalathin intervention | Cardioprotection | Aspalathin activated Adipoq and modulated the expression of Ppar γ and Srebf1/2- decreasing inflammation <i>via</i> Il6/Jak2 pathway- which increased expression of Bcl2 preventing myocardium apoptosis. |

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| Ros-Santaella JL- et al. (2017) [36] | Boar semen | Four concentrations both of fermented and unfermented Rooibos extracts | Sperm function | Rooibos extract enhanced sperm velocity- protected acrosome structure- and preserved membrane integrity during semen storage. |
| Johnson R- et al. (2017) [74] | <i>In vitro</i> | Aspalathin intervention | Cardioprotection | Aspalathin increased glucose oxidation and modulated fatty acid utilization and induced a favourable substrate shift in H9c2 cardiomyocytes exposed to high glucose. |
| Nash LA- et al (2016) [52] | Saos2 cells | Rooibos- green and black tea -normalized to 1 or 10 µg / mL gallic acid equivalents. | Bone health | Green- black and Rooibos tea improved osteoblast activity at a low level. |
| Kamakura R- et al. (2015) [40] | Obese diabetic mice | Green Rooibos extract | Blood glucose- antidiabetic potential | Green Rooibos extract suppressed the increase in fasting blood glucose levels in type 2 diabetic model mice. |
| Ku SK- et al. (2015) [42] | Human umbilical vein endothelial cells and mice | Aspalathin and nothofagin from green Rooibos | High glucose-induced inflammation | Treatment of aspalathin or nothofagin inhibited high glucose-mediated vascular hyperpermeability- adhesion of monocytes toward human umbilical vein endothelial cells- and expression of cell adhesion molecules. |
| Lee W- et al. (2015) [65] | Human umbilical vein endothelial cells and mice | Aspalathin and nothofagin from green Rooibos | Anti-inflammatory functions | Aspalathin and nothofagin possess anti-inflammatory functions are could be a useful therapy for vascular inflammatory diseases. |
| Mazibuko SE- et al. (2015) [47] | <i>In vitro</i> - using cultured adipocytes | Treated with green Rooibos extract or aspalathin | Glucose and lipid metabolism | At a protein level green rooibos extract and aspalathin suppressed markers of insulin resistance i.e. insulin receptor substrate one. |
| van der Merwe JD- et al. (2015) [29] | Male Fischer rats | Aspalathin-enriched green Rooibos extract | Antioxidant activity | Glutathione reductase activity significantly ($p < 0.05$) increased after 28 days- while glutathione content was decreased after 90 days- suggesting an altered glutathione redox cycle. |
| Waisundara & Hoon (2015) [30] | <i>In vitro</i> models of diabetes and cancer | Rooibos tea | Oxidative stress- diabetes- cancer | The Rooibos tea extract was observed to have increased the CAT and SOD activities in two <i>in vitro</i> disease models. |
| Ajuwon OR- et al. (2014) [31] | Male Wistar rats | Fermented Rooibos extract | Hepatoprotection- Oxidative stress | Aqueous Rooibos extract attenuated LPS-induced liver injury possibly by modulating oxidative stress and suppressing pro-inflammatory cytokines formation. |
| Ayeleso AO- et al. (2014) [37] | Diabetic rats | Aqueous Rooibos tea extract (2%) for 7 weeks. | Sperm function | Significant ($p < 0.05$) elevated levels of wobble and sperm linearity were observed following Rooibos tea extract treatment |
| Canda BD- et al. (2014) [32] | Forty male Wistar rats | Fermented Rooibos- unfermented rooibos- a rooibos-derived commercial supplement- or water. | Oxidative stress- Antioxidant activity | Fermented Rooibos caused a decrease ($p < 0.05$) in superoxide dismutase activity. |
| Dludla PV- et al. (2014) [33] | Diabetic rats | Aqueous extract of fermented Rooibos | Oxidative stress | Aqueous extract of fermented Rooibos protected cardiomyocytes- derived from diabetic rats- against experimentally induced oxidative stress and ischemia. |
| Hong IS- et al. (2014) [34] | Laboratory model | Rooibos tea | Oxidative stress | Rooibos tea appears to (i) reverse the increase in stress-related metabolites (ii) prevent lipid peroxidation- (iii) restore stress-induced protein degradation- (iv) regulate glutathione metabolism and (v) modulate changes in the activities of antioxidant enzymes. |

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|----------------------------------|---|---|--|--|
| Opuwari CS- et al. (2014) [38] | Male rats | Fermented Rooibos | Sperm function | Fermented Rooibos significantly improved sperm vitality ($p < 0.01$)- but caused a significant increase in spontaneous acrosome reaction ($p < 0.05$)- whereas unfermented did not. |
| Sanderson M- et al. (2014) [50] | <i>In vitro</i> | Fermented Rooibos | Obesity prevention | Hot water soluble solids from fermented Rooibos inhibited adipogenesis- suggesting its potential in preventing obesity. |
| Schloms L- et al. (2014) [75] | Rats | Rooibos | Inflammation | <i>In vivo</i> studies demonstrate that Rooibos significantly decreased glucocorticoid levels in rats and steroid metabolite ratios linked to metabolic disorders. |
| Mazibuko SE- et al. (2013) [76] | <i>In vitro</i> using skeletal muscle cells | Treated with aspalathin-enriched green (unfermented) Rooibos extract | Insulin resistance | Rooibos attenuated palmitate-induced insulin resistance in C ₂ C ₁₂ skeletal muscle cells. |
| Awoniyi DO- et al. (2012) [39] | Male Wistar rats | Fermented Rooibos- 'green' Rooibos- Chinese green tea- Rooibos supplement- green tea supplement or water. | Sperm function | Both Rooibos extracts offered a measure of protection against induced oxidative damage by increasing the antioxidant defence mechanisms improving the sperm quality and function. |
| Muller CJ- et al. (2012) [41] | <i>In vitro</i> | Rooibos extract high in aspalathin content | Hypoglycaemic potential | <i>In vivo</i> the extract sustained a glucose lowering effect comparable to metformin over a 6h period after administration (25mg/kg body weight (BW)) to STZ-induced diabetic rats. |
| Pantsi WG- et al. (2011) [77] | Male Wistar rats | Aqueous Rooibos and green tea | Cardioprotection | Results demonstrate the cardio-protective properties of aqueous Rooibos extracts <i>via</i> the inhibition of apoptosis which can possibly be related to its flavonol content. |
| Sissing O- et al. (2011) [58] | Male rats | Rooibos- Honeybush and Camellia sinensis teas | Esophageal papillomas | The mean total papilloma size was reduced by unfermented Rooibos (87%). |
| Hendricks R- et al. (2010) [54] | Whole blood culture assays | Rooibos tea and Camellia sinensis | Immune function | Rooibos and black tea modulate immune function <i>in vitro</i> . Rooibos tea stimulated whole blood cultures induced higher Interleukin-6- lower Interleukin-10- and had no effect on Interferon gamma secretion |
| Baba H- et al. (2009) [10] | Seven-week-old Wister rats | Rooibos tea and water. | Oxidative stress- Antioxidant activity | Serum SOD levels were significantly higher in the Rooibos group compared to the controls ($p < 0.05$). |
| Kawano A- et al. (2009) [48] | Type 2 diabetes model mice <i>in vivo</i> | Aspalathin- a green Rooibos tea component | Antidiabetic potential | Aspalathin appears to have beneficial effects on glucose homeostasis in type 2 diabetes by stimulating glucose uptake in muscle tissues and insulin secretion from pancreatic beta-cells. |
| Marnewick JL- et al. (2009) [61] | Rat liver | Unfermented and fermented Rooibos | Chemo protection | Unfermented rooibos significantly ($p < 0.05$) to marginally ($p < 0.1$) reduced the total number of foci (>10microm). Fermentation seems to reduce the protective effect of the herbal teas. |
| Gilani AH- et al. (2006) [59] | Isolated tissue preparations | Aqueous extract of Rooibos tea | Antispasmodic effects | Rooibos tea possessed a combination of dominant K (ATP) channel activation and weak Ca(++) antagonist mechanisms justifying its use in hyperactive gastrointestinal disorders. |
| Khan AU- et al. (2006) [60] | Isolated tissue preparations | Aqueous extract of Rooibos tea | Bronchodilator- antispasmodic | The bronchodilator- antispasmodic and blood pressure lowering effects of Rooibos tea appear to be mediated predominantly through K (ATP) channel activation with the selective bronchodilatory effect. |

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|--------------------------------------|--|--|------------------------|--|
| Ulicná O- et al. (2006) [49] | Streptozotocin-induced diabetic rats | Aqueous and alkaline extracts of Rooibos tea | Antidiabetic potential | Antioxidant compounds in rooibos tea partially prevent oxidative stress and they are effective in both hydrophobic and hydrophilic biological systems. |
| van der Merwe JD- et al. (2006) [78] | Comparative- <i>in vitro</i> | Rooibos and honey bush tea compared with black- oolong and green teas | Antimutagenic | Antimutagenic activity of the South African herbal teas was mutagen-specific- affected by fermentation. Unfermented Rooibos was less effective than fermented Rooibos |
| Lee EJ- et al. (2004) [79] | DNA strand scission | Rooibos tea | Antioxidant activity | Result suggests that total soluble phenolics- specially flavonoid- of Rooibos tea are responsible for several kinds of antioxidant activities and preventive activity on peroxy radical induced DNA strand scission. |
| Kucharská J- et al. (2004) [35] | Rat model of carbon tetrachloride-induced liver damage | Rooibos tea | Oxidative stress | Rooibos tea restored liver concentrations of CoQ9H2 and alpha-tocopherol and inhibited the formation of MDA. |
| Marnewick JL- et al. (2004) [62] | Male Fischer rats | Unprocessed (not oxidized)- processed (oxidized) rooibos- honey bush- green and black teas | Mutagenic response | The mutagenic response of aflatoxin B1 against Salmonella strain TA 100 was significantly ($p<0.05$) inhibited by cytosolic fractions from rats treated with processed and unprocessed herbal teas. |
| Ulicná O- et al. (2003) [53] | Rat model of liver injury | Rooibos tea | Hepatoprotection | Rooibos tea showed histological regression of steatosis and cirrhosis in the liver tissue with a significant inhibition of the increase of liver tissue concentrations of malondialdehyde- triacylglycerols and cholesterol. |
| Kunishiro K- at al. (2001) [55] | <i>In vitro</i> and <i>in vivo</i> . | Rooibos tea extract | Immune function | Rooibos tea extract may facilitate the antigen-specific antibody production through selective augmentation of IL-2 generation both <i>in vitro</i> and <i>in vivo</i> . |

Key: ATP-Adenosine Triphosphate; CAT-Chloramphenicol Acetyltransferase; DNA-Deoxyribonucleic Acid; IL-Interleukin; LDL-Low-Density Lipoprotein; LPS-Lipopolysaccharide; MDA- Malondialdehyde; ROS- Reactive Oxygen Species- SOD-Superoxide Dismutase; STZ- Streptozotocin.

effects [26]. This research suggests promise for conditions such as allergic rhinitis [22] but further investigations are needed. Additionally, its effects on bone health [51,52], cognitive health [56,57] and potential hepatoprotective effects [12,31,53] warrant further exploration in the form of human trials. Recently, a review of experimental evidence [68] concluded that blood glucose levels were significantly lower in diabetic rodent models treated with rooibos extracts providing phenolic compounds. Other work suggests that Rooibos extracts and its constituent C-glucosyl flavonoids, and Z-2-(β -D-glucopyranosyloxy)-3-phenylpropenoic acid may elicit positive effects on cellular oxidative stress, inflammation and transcription factors that control genes regulating glucose and lipid metabolism helping to attenuate features of metabolic disease [69].

In the present review human subjects tended to drink Rooibos beverages after they had been infused for approximately 10 minutes [20,23,25]. Recently, from a consumer stance the ideal 'optimal cup' of Rooibos tea has been defined as one that had been seeped for 10 minutes or longer [70]. Unfortunately, recent research shows that only 15.9% of respondents consumed an 'optimal cup' of Rooibos in an amount that enables its potential cardioprotective health benefits to be provided (defined as a minimum of 4 to 6 cups per day) [70]. Interestingly, compared with cold and regular-brewed Rooibos infusions of unfermented/green and red Rooibos prepared by boiling have the highest antioxidant capacities and total polyphenol profiles

[9]. Such findings suggest that more information needs to be imparted to consumers' regarding preparation methods and the potential health benefits that drinking Rooibos tea could bring.

With regard to limitations and future research directions greater uniformity is needed in forthcoming studies. For example, some studies used fermented and others unfermented Rooibos extracts or infusions the fermented form appeared to have stronger impact on some health effects [38,51]. Others used Rooibos tea and Rooibos 'extracts' or unfermented/green Rooibos. Production seasons and grade quality could also alter the phenolic profiles and antioxidant capacity of Rooibos samples and should be considered [66]. Future trials should also better encompass how findings could be translated into public health messages. For example, Marnewick JL, et al. (2011) [21] asked volunteers to drink six cups Rooibos tea daily for 6-weeks to study its cardiovascular effects. Similar studies are now needed for other health outcomes such as bone health, liver or brain (cognitive) function.

Considering such evidence Rooibos tea, like teas from *Camellia sinensis* (e.g. black, green and oolong tea) could be regarded as a 'general health' tea, potentially providing an array of benefits to human health and wellbeing [56] Rooibos tea is naturally slightly sweet [16] thus does not require the addition of extra sugar or artificial sweeteners. It is also caffeine free with a favourable phenolic composition [9,10]. (Table 2)

Conclusions

In conclusion previous health research has tended to focus on black or green tea. Rooibos is widely consumed in South Africa but is gaining popularity globally. This has been attributed to the fact that it is caffeine free, naturally sweet and abundant in polyphenols with potent antioxidant properties. Now, a growing body of evidence from 7 human studies and 49 laboratory studies suggests that Rooibos could be regarded as a 'general' health tea. Evidence for cardioprotective effects (especially lipid profile) looks promising, particularly as a potential adjunctive therapy. It is suggested that future research now builds on the other potential aspects of health including glycaemic, bone, liver and cognitive wellness enhancing effects that also appear to be emerging.

Disclosure

The views expressed are those of the authors alone and personnel from the UK TEA & INFUSIONS ASSOCIATION (UKTIA) had no role in writing this review.

Conflicts of Interest

The authors declare no conflicts of interest.

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