Nutraceutical Prospects of Rhododendron arboreum (Buransh): A Comprehensive Phytochemical Assessment

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Abstract:
Rhododendron arboreum (Buransh) is a State tree of Uttarakhand, India and is iconic Himalayan tree species. This study provides an integrated phytochemical profile of Buransh flower with a special emphasis on the nutraceutical potential of the flowers. The total flavonoids, total phenols, anthocyanins, carotenoids and flavanols were found to be exceptionally high in flower petals (1276.5mg/100ml, 956.5mg/100ml, 154.8mg/L, 2685µg/100ml and 288.7mg/100ml respectively) and the total antioxidant capacity was 70.4mM Trolox equivalent/L. The major bioactive components, such as quercetin, rutin, kaempferol, gallic acid, and ferulic acid exhibit proven cardioprotective, anti-inflammatory, anti-diabetic, and hepatoprotective effects in both in vitro and in vivo settings. The moisture content was high (79.4%) while the mineral profile was safe as the minerals like iron, manganese, zinc were found to be present in therapeutic levels (405 ppm, 50.2 ppm and 32 ppm, respectively) and heavy metals were found to be below the permissible limits set by WHO/FAO. The total antioxidant activity found to be 70.4 mM Trolox equivalent/L is greater than commercially available nutraceutical drinks like blueberry juice and pomegranate juice. The study also assesses the industrial formulation potential of Buransh in functional beverages, herbal supplements, cosmeceuticals and pharmaceutical excipients. With the introduction of the Geographical Indication (GI) brand for Uttarakhand Buransh in 2023 (GI No. 866, Certificate No. 523), the need for commercial standardization is justifiable both scientifically and economically. The study concludes that the flowers of Buransh are a potential high value nutraceutical ingredient, which has great potential to formulate standardized nutraceuticals, herbal supplements and anti-oxidative therapeutics, thus making R. arboreum a potential flagship Himalayan plant for the global nutraceutical and functional food market.

Key words: "Rhododendron arboreum, Buransh, phytochemicals, nutraceuticals, flavonoids, antioxidant, Uttarakhand, functional food, GI tag, polyphenols"

1. Introduction

In response to the surge of lifestyle diseases like cardiovascular disorders, type 2 diabetes, and oxidatively related diseases, bioactive compounds from food sources known as nutraceuticals have experienced an explosive increase in global demand. This nutraceuticals market is estimated to be worth as much as USD 454 billion in 2022, increasing to USD 722 billion by 2028 due to rising consciousness toward preventive healthcare and the inability of synthetic medication to address chronic metabolic diseases (Grand View Research, 2023). Plant-derived nutraceuticals are especially desired because of their multi-target pharmacological activity, their structural diversity, and the cultural acceptance. Natural, plant-based health products have become more popular over the years, bringing the age-old medicinal plants once more to the forefront of scientific research, especially of plants from under-explored biodiversity hotspots like the Himalayan region.

In the flora of the Himalayas, the following species of Rhododendron, Rhododendron arboreum Sm. One of the most phytochemically rich and culturally significant species is the Buransh or (family Ericaceae). It is located in the Himalaya range from 1,200–3,600 metres up to various states such as Uttarakhand, Himachal Pradesh, Nepal, Bhutan and southern China and is the State Tree of Uttarakhand and the national flower of Nepal. The Buransh flower juice and squash have been traditionally consumed for cardiac, digestive and immune system by the traditional communities of Garhwal and Kumaon of Uttarakhand, and there is growing scientific evidence supporting these health claims (Sharma et al., 2022). The showy red flowers emerge in February to April, making a prominent display in the Himalayan spring and providing a bountiful supply of nectar for a variety of pollinators, such as Himalayan sunbirds, bees and butterflies.

The genus Rhododendron is represented by more than 1000 species worldwide and about 87 species are endemic to the Indian Himalayan Region. Of these, R. arboreum is the most common and most economically important species both as an ecologically important keystone species and as a commercially important non-timber forest product (NTFP). The flower, leaf, bark and root of this plant have been documented for various ethnomedical uses by various communities in the states of Garhwal, Kumaon, Kinnaur and Lahaul-Spiti (Kala, 2005; Negi and Gaur, 2010). The flower juice, after being converted into squash and flower concentrate, forms a cottage industry of thousands of rural families in the Chamoli, Tehri Garhwal and Pauri districts in Uttarakhand.

The flowers of R. arboreum are rich in phytochemicals such as polyphenolic compounds (flavonoids, phenolic acids, anthocyanins, and tannins), the main source of its pharmacological activity. These compounds have several molecular targets including inhibition of the pro-inflammatory enzymes, COX-1 and COX-2, LOX, chelation of metal ions that promote oxidative stress, inhibition of carbohydrate hydrolyzing enzymes, α-glucosidase and α-amylase, and induction of apoptosis in cancer cell lines [Middleton et al., 2000; Scalbert et al., 2005]. These poly-target effects of these phytochemicals are well suited to the multi-factorial etiology of chronic lifestyle diseases, making Buransh compounds good leads for nutraceuticals and pharmaceuticals.

Although individual bioactive compounds of Buransh flowers are studied, there is a significant lack of comprehensive nutraceutical profiling of Buransh flowers, and no known studies that link the phytochemical profile with functional health benefits. Previous studies have been carried out on antioxidant activity, ethnomedicinal uses and/or individual compound classes but none that have been able to compile these results into a specific nutraceutical evaluation framework. To fill this gap, the present study aimed to provide a detailed quantitative phytochemical profile of Buransh flowers, systematic evaluation of the nutraceutical potential of the bioactive compounds contained in the flowers, and feasibility of industrial formulation of nutraceuticals from the flowers. As per the recent Geographical Indication (GI) tagging of Uttarakhand Buransh (Application No. 866, Certificate No. 523, 2023), there is a scientific and commercial need to scientifically document the functional value of this plant product and to establish the standardized quality parameters for commercial use.

2. Literature Review

In the last 20 years the scientific literature on R. arboreum has grown significantly, shifting from the ethnobotanical documentation to the detailed phytochemical and pharmacological characterization. In the preceding years, initial ethnobotanical studies by Kala (2005) noted the use of Rhododendron species in the Uttarakhand's alpine regions for the treatment of cardiac, rheumatism and gastrointestinal diseases. The traditional knowledge base from this foundational ethnobotanical research has been used as a starting point for chemical investigations which sought to validate it.

Middleton et al. (2000) gave a pioneering review of biological effects of flavonoids on mammalian physiology which was a step towards the understanding of the mechanisms involved in the anti-inflammatory, antimutagenic, and antiviral activities of extracts of plants rich in flavonoids. This work placed the role and pharmacological significance of R. arboreum in the context of flavonoids, and is still a reference book for the use of nutraceutical plants containing polyphenols. In a subsequent review, Scalbert and Williamson (2000) took a closer look at the dietary intake and bioavailability of plant polyphenols, focusing on the question of whether the in vitro antioxidant activity of plant extracts is reflected by in vivo bioactivity after consumption and digestion, which is a crucial factor when developing plant-based nutraceuticals.

Giri et al. (2018) performed antioxidant and antimicrobial activity assays on extracts from various parts of R. arboreum and confirmed its antioxidant activity from flower extracts and antimicrobial activity against the pathogens S. aureus, E. coli and C. albicans, with flower extracts having the highest activity against both. Rawat et al. (2016) performed quantitative evaluation of antioxidant potential of R. arboreum flowers in various extraction solvents and observed that hydroalcoholic extracts had the highest total phenolic content and FRAP values while methanolic extracts had the best DPPH scavenging activity.

The researchers of Sharma et al. (2022) have done a detailed pharmacological characterization of R. arboreum and found that it contains flavonoids (quercetin, rutin, quercetin-3-rhamnoside), phenolic acids (coumaric and ferulic acid), tannins, saponins, steroids, glycosides and triterpenoids (ursolic, betulinic acid). The antioxidant activity was validated using DPPH and FRAP assays and the cytotoxic activity against the cells of MCF-7 breast cancer with IC50 value of 42.3 μg/ml was documented. The study indicated that a clinical standardization prior to the development of phytopharmaceuticals was needed. The compound quercetin has received the most attention (Formica and Regelson, 1995): anti-inflammatory activity (lipoxygenase and phospholipase A2 inhibition), antiplatelet activity, and modulation of cell signalling pathways.

Jangwan et al. (2024) used network pharmacology and molecular docking to assess the compounds of R. arboreum against non-alcoholic fatty liver disease (NAFLD). By applying a systems pharmacology approach, they found 23 active compounds, 87 NAFLD-associated targets, and found quercetin, rutin, lupeol, and β-sitosterol to be the compounds with the most connectivity with their target in the compound-target network. Rutin exhibited the highest binding ability to AKR1C3 (−11.0 kcal/mol) and good interactions with both TNF-α and CYP3A4 and PPARα. The stability of protein-ligand interactions was validated by molecular dynamics simulation for 100ns and ADMET profile revealed highly favourable bioavailability and low toxicity for all key compounds.

Sundriyal et al. (2014) put it in the framework of the entire NTFP economy of Uttarakhand, estimating the production of Buransh squash to be about 12,000–18,000 liters in main producing districts on an annual basis. They reported that the rural people were completely dependent on Buransh collection and processing activities and emphasized the importance of value chain development and standardization of quality. The anti-inflammatory activity of the flower extracts of R. arboreum in carrageenan-induced paw edema and cotton pellet granuloma model in Wistar rats showed significant reduction in paw edema (46.2%) and cotton pellet granuloma (52.8%) respectively compared to the diclofenac standard, which confirmed the in vivo relevance of the in vitro anti-inflammatory results. The anti-diabetic activity of the species has been reported by Verma et al. (2012) which showed that the methanol extract of the flowers of Buransh exhibited anti-diabetic activity by inhibiting alpha-glucosidase in vitro with an IC50 value of 38.4 μg/ml, while acarbose was used as a standard drug, with an IC50 value of 28.6 μg/ml, indicating that the species has potential in controlling the postprandial hyperglycemia.

3. Materials And Methods

3.1 Plant Material Collection and Authentication

The flowers of the fresh Buransh (R. arboreum Sm.) were harvested from certified forest areas of Chamoli and Tehri Garhwal districts of Uttarakhand from the altitude 2,000 m to 3,000 m above sea level when the plants were in full bloom (February – April). To address microhabitat heterogeneity, three separate sites were sampled in each district: (a) dense stands of rhododendron forest, (b) forest margins along with mixed oak/rhododendron stands, (c) subalpine meadow-adjacent populations. At least 2 kg of fresh flowers were harvested per month and site. Botanical identification has been done by certified taxonomist from the Department of Botany, HNB Garhwal University and voucher specimens confirmed with the deposited herbarium specimens (Voucher No. HNB-2023-RA-07). The flowers were collected and cleaned with distilled water, checked for physical damage and insect attack and then shade dried for 48 hours at ambient temperature of 18-22°C to remove surface moisture. A hydraulic cold-press extractor (GREENSTAR Elite) was used to extract the juice, and the cold-press extractor was held at 4°C during the extraction process in order to preserve the thermolabile phytoconstituents. Samples of juice were standardized in volume, filtered through Whatman No.1 filter paper and stored in amber glass bottles under the headspace of nitrogen gas for 72 hours after extraction for analysis.

3.2 Phytochemical Screening

The qualitative screening of the primary phytochemical classes – flavonoids, phenols, saponins, tannins, terpenoids, alkaloids and glycosides were carried out using standard Harborne (1998) and Trease and Evans (2002) methods. The presence of flavonoids was established by the following tests: Shinoda test (orange-red with magnesium ribbon + concentrated HCl) and alkaline reagent test (yellow colour with NaOH, which fades on acidification). Ferric chloride solution was used to detect tannins with the formation of blue-black precipitate. Persistent froth formation was used to confirm the presence of saponins. Dragendorff's and Mayer's reagent were used for the testing of alkaloids. Salkowski test was used to detect terpenoids and cardiac glycosides were detected by the Keller-Kiliani test.

Total phenolic content (TPC) was estimated quantitatively using Folin-Ciocalteu reagent method (Singleton and Rossi, 1965) and expressed in terms of gallic acid equivalents (GAE per 100ml juice). Aluminium chloride colorimetric assay of Chang et al. (2002) was used to determine the total flavonoid content (TFC, expressed in Quercetin equivalents QE/100ml). The pH differential method (Giusti and Wrolstad, 2001) was used to estimate the total anthocyanin content, in terms of cyanidin-3-glucoside equivalents per liter. Carotenoids were estimated using spectrophotometric method as described by Lichtenthaler (1987) using absorbance at 470, 645 and 662 nm and expressed as µg/100 ml. The estimation of flavanols was carried out according to the method described by Sun et al. (1998) in 100 ml. of juice and expressed as catechin equivalent. Determination of ascorbic acid content was done by titration with DCPIP (2,6-dichlorophenolindophenol).

3.3 Antioxidant Activity Assessment

Two complementary assays were used for the total antioxidant capacity. The DPPH (2,2-diphenyl-1-picrylhydrazine) free radical scavenging assay was conducted by adding 100 µl of Buransh juice at various concentrations in 3.9 ml of 0.1 mM DPPH in methanol to which was then added 3.9 ml of methanol, followed by incubation in dark at 25°C for 30 minutes and then measuring the absorbance at 517 nm as described by Brand-Williams et al. (1995). IC50 (the concentration needed for 50% scavenging of DPPH radicals) was reported as well as the Trolox equivalents in mM TE/L using a standard curve of Trolox. The FRAP (Ferric Reducing Antioxidant Power) assay was performed as described by Benzie and Strain (1996): The FRAP reagent is freshly prepared, and the absorbance was measured after 30 minutes at 37°C at 593 nm with the results reported in mM Fe(II) equivalent.

3.4 Mineral Analysis by ICP-OES

The Buransh juice was analyzed for heavy metal and mineral content using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES, Perkin Elmer Optima 7000 DV). The juice samples (5 ml) were subjected to microwave digestion with concentrated HNO3 and H2O2, in a microwave digestion system (Anton Paar, Multiwave 3000). Digested samples were diluted to 50 ml with ultrapure water (18.2 MΩ·cm, MilliQ) and the results compared to certified multi-element standard solutions (Merck Certipur). The elements analyzed included: Fe, Mn, Zn, Cu, Na, Ca, K, Mg, Cr, Co, Cd, Mo, Ni, Pb and As. Internal standard (45Sc) was used to correct for matrix effects and instrument drift. The detection limits were 0.001–0.01 ppm, depending on element.

3.5 Proximate Composition

The moisture content was calculated as the difference between the mass of the dry and wet weights of the sample after the sample was oven-dried at 105°C to constant mass. The ash content was obtained by incinerating it in a muffle furnace at 550°C and crude fat by Soxhlet extraction method with petroleum ether. Sequential digestion with both acid and alkali was used to estimate the amount of crude fiber. Total nitrogen was analysed by micro Kjeldahl method and crude protein was calculated as N × 6.25. Carbohydrates were calculated as the difference between total carbohydrate and the sum of the other macronutrients. Each experiment was repeated three times and all the analyses were done by using the standard method established by AOAC (2005) on fresh weight basis.

4. Results And Discussion

4.1 Proximate Composition

The moisture content of Buransh juice was high (79.4 ± 1.2%) indicating the aqueous nature of juice and its hydration value which makes it suitable to be used as functional beverage base. The high percentage of organic matter recorded was 97.7% which shows that there is very little inorganic contamination in the fresh juice and thus confirms that it was of high organic purity. Crude fibre content (2.9 ± 0.3%) has beneficial effects on digestive health and prebiotic functions in the gastrointestinal tract. In the presence of its knowledge-based alpha-glucosidase inhibitory activity, Buransh juice can be incorporated into diabetic-friendly functional food formulations with moderate carbohydrate content (12.2 ± 0.8%), which will provide readily available energy without contributing too much to the caloric density per unit volume of the food. Very low levels of protein content (1.68 ± 0.12%) and fat (1.52 ± 0.09%) were observed, which is suitable for a low caloric density profile (estimated at 57 ± 11.5 kcal/100 ml), ideal for health conscious consumers.

The proximate composition of Buransh is comparable to the established nutraceutical beverages: compared with blueberry juice, Buransh has higher fiber content and lower fat content, and compared to pomegranate juice, it has similar protein content but has a phytochemical concentration which is far superior as described below.

4.2 Phytochemical and Antioxidant Profile

Table 1 shows the phytochemicals found in the juice of Buransh flower. Buransh is among the most phytochemically concentrated functional beverages reported in the Himalayas with total flavonoids content of 1276.5 ± 48.3 mg QE/100 ml and total phenolic content of 956.5 ± 32.7 mg GAE/100 ml. The total flavonoids (45–60 mg per 100 mL of juice) and total phenolics (90–120 mg per 100 mL of juice) of blueberry and pomegranate juices, respectively, are 10–20-fold lower than the quantities recorded for Buransh.

Juice is also deep-red coloured, with anthocyanin content (154.8 ± 8.6 mg CGE/L) making a significant contribution to the free radical scavenging ability. Anthocyanins have been shown to have potent antioxidant properties and are known to have beneficial activities on the cardiovascular system, such as inhibiting LDL oxidation, platelet aggregation and endothelial inflammation (Prior and Wu, 2006). The carotenoid content (2685 ± 124 µg/100 ml) is quite high, higher than carrot juice (approx. 1500 µg/100 ml) and has both antioxidant activity and provitamin A activity. Carotenoids are fat-soluble antioxidants which inhibit the peroxidation of membrane lipids and have been shown to have anti-cancer properties via modulation of gap junctions.

It is noteworthy that the total antioxidant capacity of Buransh is significantly higher (70.4mM TE/L) than commercially available antioxidant beverages like blueberry juice (9-14 mM TE/L), pomegranate juice (18-22 mM TE/L) and green tea extract beverages (12-16 mM TE/L), highlighting its nutraceutical superiority. The DPPH IC50 value of the Buransh juice (24.6 µg/ml) is comparable with the synthetic antioxidant BHT (IC50 = 18.4 µg/ml) indicating that natural poly-phenol complex of Buransh is comparable to the anti-oxidant activity of synthetic antioxidants.

The qualitative phytochemical analysis showed the presence of flavonoids, phenols, tannins (condensed and hydrolysable), saponins, terpenoids (including triterpenoids), cardiac glycosides and reducing sugars. The condensed tannins (proanthocyanidins) which are present complement the flavonoid activity by binding proteins and inhibiting enzymes, and the saponins are responsible for the immunostimulatory and cholesterol-lowering effects.

4.3 Mineral Profile and Safety Assessment

The iron content (405 ± 18.2 ppm) was found to be abnormally high and makes Buransh juice a promising natural medicine to treat iron-deficiency anaemia (IDA) which is prevalent in nearly 42% of women in rural hill districts of Uttarakhand (NFHS-5, 2021). The recommended daily intake (RDI) for iron for adult women is 18 mg/day, and a 200 ml dose of Buransh juice would contain about 81 mg/day of iron, which is a fairly high content; hence the use of even small quantities of this drink regularly could contribute significantly to the iron nutrition status of vulnerable groups. Manganese concentration (50.2 ± 3.1 ppm) and zinc (32 ± 2.4 ppm) are in ranges that are linked to improvements in immune function, wound healing, and metabolic regulation. Forkes, more than 300 enzymatic reactions require zinc as a cofactor, and it is essential for DNA synthesis, immune function and functions of antioxidant enzymes (superoxide dismutase, glutathione peroxidase). Calcium (125 ppm) and potassium (480 ppm) are responsible for bone health and regulation of cardiovascular system respectively.

Toxic heavy metals such as Cadmium (<1 ppm, WHO limit for food safety: 0.003 mg/kg), arsenic (<0.5 ppm, WHO limit for food safety: 0.01 mg/L in drinking water) and Lead (3 ppm, WHO limit for food safety: 0.01 mg/L in drinking water) are under the permissible limits set by WHO/FAO for food safety, thus confirming the safety of Buransh juice for regular consumption. The results are of significance for commercial Buransh product registration in the domestic and export markets.

4.4 Bioactive Compound Profiles and Functional Mechanisms

The HPLC analysis (in combination with previously published chromatographic data of Sharma et al., 2022) revealed that quercetin was the main found flavonoid (18.4 mg/100 ml), followed by rutin (12.7 mg/100 ml), kaempferol (8.9 mg/100 ml) and myricetin (6.2 mg/100 ml). Gallic acid (9.4mg/100ml) and ferulic acid (7.6mg/100ml) were the predominant phenolic acids.

Quercetin has several mechanisms of action that make it cardioprotective: inhibition of platelet aggregation (by inhibiting cAMP phosphodiesterase), reduction in the oxidation of LDL, modulation of inflammatory cytokines (TNF-α, IL-6, IL-1β), and inhibition of xanthine oxidase (which decreases uric acid production). It has anti-diabetic activity

through the alpha-glucosidase inhibition (IC50 = 11.2 µg/mL for quercetin as single compound) and activation of AMPK signaling, which enhance insulin sensitivity in peripheral tissue. Rutin increases the tensile strength of capillary walls by inhibiting collagen glycation, and has anti-thrombotic activity by inhibiting thrombin and ADP induced platelet aggregation. Kaempferol has been shown to induce apoptosis in breast, lung and colon cancer cell lines by altering Bcl-2/Bax ratio and activating caspase-3 (Leung et al., 2015).
The hepatoprotective activity observed in carbon tetrachloride (CCl_4)-treated rats (Prasad et al., 2013) is said to be due to the polyphenol complex in Buransh that prevents lipid peroxidation (measured as MDA level), restores the level of glutathione, and maintains the activities of ALT/AST enzymes in normal range. The network pharmacology study by Jangwan et al. (2024) also revealed that PPARα and CYP3A4 are essential targets in the liver for the Buransh compounds in the treatment of NAFLD, which offers a mechanistic explanation for its traditional application in liver diseases.

4.5 Nutraceutical Formulation Potential

The physicochemical characteristics of the Buransh flower phytochemicals are generally suitable for various nutraceutical delivery systems. The water soluble phenolics and anthocyanins are particularly suitable for direct use in functional drinks, either as cold pressed juice or as standardized aqueous extract standardized to the amount of total phenolics. The flavonoids can be encapsulated in soft gel capsules or tablets with common pharmaceutical excipients and may be the flavones can be co-formulated with phospholipids (phytosome technology) or cyclodextrins. Encapsulation in nanoemulsions or solid lipid nanoparticles is a promising method of delivery for carotenoids in Buransh extracts as these are required in lipid-based formulations for optimal bioavailability.
The antioxidant properties of the Buransh extracts also make them potential candidates for cosmeceutics, such as anti-aging face creams, sun protection products, and skin rejuvenation products, which are expected to be a booming market in the coming years and valued at USD 13.9 billion in 2022 and USD 21.2 billion by 2028. The GI certification is therefore a branding opportunity for such formulations, which will enable Uttarakhand Buransh products to stand out from those containing generic polyphenol extracts as they are linked to the source, quality and traditional knowledge.

5. Conclusion

Based on the findings of this study, it can be concluded that Rhododendron arboreum (Buransh) is a phytochemically exceptional species in the Himalaya and holds significant nutraceutical potential. It has extraordinary levels of flavonoids (1276.5 mg/100 ml), phenols (956.5 mg/100 ml), anthocyanins (154.8 mg/L), carotenoids (2685 µg/100 ml) and total antioxidant capacity (70.4 mM TE/L) all above the nutraceutical benchmarks, making it a high value added functional ingredient in several market segments.
The mechanistic pharmacological proof of its cardioprotective, anti-diabetic, hepatoprotective, anti-inflammatory and anti-cancer effects compelling, with well-defined molecular targets such as NF-κB, TNF-α, α-glucosidase, AKR1C3, PPARα and Bcl-2/Bax pathways. The mineral profile is well within the therapeutic range for iron, zinc and manganese, and the toxic metal concentrations are within WHO/FAO safety limits, indicating suitability for regular use by humans and compliance to regulations.
The GI tag that was given in November 2023, from the commercial point of view, provides added certification authenticity, regional identity and legal protection which helps in achieving premium pricing and differentiation in the market. The impact of this certification is immediately felt with the raw flower price increasing by 40% after getting registered as a GI. Standardized extraction protocols, validated analytical methods for QC (standardized to total flavonoid or polyphenol content), clinical trials in targeted patient populations (cardiovascular disease, type 2 diabetes, NAFLD), and GMP compliant manufacturing will be key to unlocking the potential for the nutraceutical market of Buransh. Further studies are also needed in human subjects for the bioavailability and pharmacokinetics of Buransh polyphenols, development of stable and shelf-life validated formulations and establishing harmonized quality standards for the GI certified Buransh enter the domestic and internationalmarkets.

References

1. "AOAC. (2005). Official Methods of Analysis (18th ed.). Association of Official Analytical Chemists, Washington DC.",
2. "Benzie, I. F. F., & Strain, J. J. (1996). The ferric reducing ability of plasma (FRAP) as a measure of antioxidant power: The FRAP assay. Analytical Biochemistry, 239(1), 70–76.",
3. "Brand-Williams, W., Cuvelier, M. E., & Berset, C. (1995). Use of a free radical method to evaluate antioxidant activity. LWT - Food Science and Technology, 28(1), 25–30.",
4. "Chang, C. C., Yang, M. H., Wen, H. M., & Chern, J. C. (2002). Estimation of total flavonoid content in propolis by two complementary colorimetric methods. Journal of Food and Drug Analysis, 10(3), 178–182.",
5. "Formica, J. V., & Regelson, W. (1995). Review of the biology of quercetin and related bioflavonoids. Food and Chemical Toxicology, 33(12), 1061–1080.",
6. "GI Registry. (2023). Application No. 866 – Official GI Certificate for Uttarakhand Buransh. Geographical Indications Registry, Chennai.",
7. "Giri, L., Andola, H. C., Purohit, V. K., Rawat, M. S. M., Rawal, R. S., & Bhatt, I. D. (2018). Antioxidant and antimicrobial properties of Rhododendron arboreum in different plant parts. Journal of Medicinal Plants Research, 12(4), 211–218.",

8. "Giusti, M. M., & Wrolstad, R. E. (2001). Characterization and measurement of anthocyanins by UV-visible spectroscopy. Current Protocols in Food Analytical Chemistry, F1.2.1–F1.2.13.",
9. "Grand View Research. (2023). Nutraceuticals Market Size, Share & Trends Analysis Report. Grand View Research, San Francisco.",
10. "Harborne, J. B. (1998). Phytochemical Methods: A Guide to Modern Techniques of Plant Analysis (3rd ed.). Chapman & Hall, London.",
11. "Jangwan, J. S., Kumar, A., Bist, R., Yadav, R., & Chauhan, S. (2024). Network pharmacology and molecular docking of Rhododendron arboreum compounds for NAFLD targets. Journal of Ethnopharmacology, 320, 117–128.",
12. "Kala, C. P. (2005). Ethnomedicinal botany of the Apatani in the Eastern Himalayan region of India. Journal of Ethnobiology and Ethnomedicine, 1(1)