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HISTORICAL NOTE

Vṛkṣāyurveda: Exploring ancient agricultural methods in modern context

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Abstract
The primary objective of this study was to explore and highlight the depth and richness of India's traditional agricultural knowledge, with a specific focus on *Vṛkṣāyurveda*, an ancient *saṃskṛta* treatise on agriculture. The study aimed to understand how these age-old principles of agriculture, rooted in sustainable practices and ecological balance, continue to hold relevance in today's context of environmental challenges and the search for sustainable farming solutions. The study included insights from contemporary scientific experiments and field trials that have tested and validated some of these ancient methods. Findings indicate that the Indian Knowledge System (IKS) in agriculture was focused on a comprehensive framework promoting biodiversity, resource conservation, and community health. Sustainable practices derived from *Vṛkṣāyurveda* have shown promising outcomes when integrated into modern organic and natural farming systems. The study concludes that traditional agricultural knowledge, especially as documented in *Vṛkṣāyurveda*, remains a valuable resource. Its integration into contemporary farming can foster sustainability, resilience, and ecological harmony.

Keywords *Vṛkṣāyurveda* · Sustainable agriculture · Organic farming · Indian Knowledge System

1 Introduction

Agriculture supports 60–70% of India's population and was once sustainable through traditional practices. The shift to European methods and the Green Revolution boosted food production but caused soil degradation, pollution, and loss of sustainability. *Vṛkṣāyurveda* offers eco-friendly alternatives. Integrating traditional methods, especially for smallholders, and policy reforms in agricultural education and research are essential to support sustainability and achieve Sustainable Development Goals (SDGs) (Beniwal et al., 2020). Agricultural practices have been a part of India's history since the dawn of time. *Āyurveda* is a healing method based on the use of medicinal plants. Nowadays, there is a growing demand for herbs, leading to plant exploitation, which results in habitat loss. As a result, sustainable ways for cultivating and preserving medicinal plants should be devised (Shubhashree et al., 2018, 2020). Various *āyurvedika* and *kṛṣiśāstra* texts describe various methods for plant development. There is a need to employ the ideas of the *ācārya* to improve farming practices sustainably (Chattopadhyay, 2007; Ramchandra, 1993; Yln, 2012).

Vrkshāyurveda is a branch of *Āyurveda* that deals with plant life. It covers gardening, planting, nutrition, plant diseases, and treatments (Meshram & Meshram, 2019; Mishra et al., 2020). Ancient Indian texts such as the Vedas, Kauṭilya's *Arthaśāstra*, *Agnipurāṇa*, *Kṛṣiparāśara*, *Bṛhatsaṃhitā*, *Upavanavinoda*, Surapal's *Vṛkṣāyurveda*, and others describe the concept of *Vṛkṣāyurveda*. Plants and their various purposes are mentioned in Vedic literature, such as the *saṃhitās, āraṇyaka, upaniṣads, and vedāṃgas*. The term *Vṛkṣāyurveda* first appears in the *Arthaśāstra* of Kauṭilya. The employment of this knowledge for agricultural purposes circa 320 BCE indicates that it was a well-established discipline. By 550 BCE, *Vṛkṣāyurveda* had established itself as a unique field (Basavaraja, 1927; Majumdar & Benerji, 1960; Mishra, 2017; Nene, 2012; Sadhale & Nene, 2009; Shreevidya and Anand, 2022).

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2 Suitable land and soil for cultivation

Many works of literature begin with a statement about the value of flora. This stresses the significance of biodiversity protection. Surapal considers *vṛkṣa* to be on par with humans, if not more so. He claims that planting a tree is equivalent to having ten sons. After that, there is a mention of plants that can be grown around the house. There are both good and bad evils associated with this. Before we start cultivating, we need to know about the propagation method, adequate soil, and climatic conditions for culture, all of which contribute to increasing productivity (Srikanth, 2015).

The text mentions that suitable soil can be identified based on the texture, colour, and taste. *Jāṃgalā, anūpā*, and *sādhāraṇa* are the three types of soil. The *jāṃgalā* is found in arid regions, the *anūpā in* marshy, swampy lands, and the *sādhāraṇa in* other places. *Śobhāṃjanā (Moringa oleifera), śrīphalā (Aegle marmelos), saptaparṇā (Alstonia scholaris), sephalikā (Nyctanthes arbortristis), śamī (Prosopis cineraria), karīrā (Capparis aphylla), karakaṇḍu (Zizyphus sativa), nimbā (Azadiracta indica), and aśokā (Saraca asoca)* are some of the plants that can be grown in a *jāṃgalā deśa.*

Panāsā (Artocarpus hetreophylla), lakucā (Artocarpus lakuca), tālī (Borasses flabillifer), vāmasā (Bambusa arundinaceae), jambū (Eugenia jambolana), tilakā (Wendlandia heynei), vata (Ficus benghalensis), kadamba (Anthocephals kadamba), āmaḍā (Spondias Mangifera), kharjurā (Phoenix dactylifera), pūga (Areca catechu), kadalī (Musa sapientum), tiniśa (Ougenia oojeinensis), mṛdvīkā (Vitis vinifera), ketakī (Pandanus odorattis), nārikela (Cocos nucifera) are some of the plants that may be planted in *anūpā deśa*.

In *Sādhāraṇa deśa,* plants like *bījapūra (Citrus medica), punnāga (Calophyllum inophyllum), campaka (Michelia champaka), āmra (Mangifera indica), gaṃdhamālatī (Aganosma caryophyllata), priyaṅgu (Callicarpa macrophylla), dāḍima (Punica granatum)* (Ramchandra, 1993).

If plants are cultivated in their proper soil, their production will be higher. There is also a mention of methods for predicting subsurface water availability by assessing the presence of particular plants in a field. This idea can also be used in a field to dig a well or pond for watering plants (Singh, 2023).

3 Method of propagation

Plants are divided into four orders: *vanaspati, vānaspatya, auṣadha*, and *viruddha* according to their properties. Plants can be propagated in a variety of ways, including seeds, stem cuttings, roots, grafting, apical parts, and leaves. Seed propagation is fairly common. Propagation by bulbous roots, underground stems, and cuts is mentioned in the *Arthaśāstra*. According to the *Bṛhatsaṃhitā*, grafting is preferable to stem cuttings. One method involves placing a cutting from one plant into the root of another plant that has been separated from its trunk. The second method involves putting a cutting from one tree into the stem of another; the cutting is referred to as a scion, while the parent plant is referred to as a stock. Seeds are used to cultivate *haridrā, suṃthī, vākā, ativiśā, kaṭurohiṇī, usira, jambū, vilva, āmra, madhuka, priyaṃgu, nāgakesara,* and *punnāga*—cuttings of *tāmbula, siṃdhuvara tagara*. Reeds and sugarcane are grown from the joints, whereas *dāḍima, paṭola, plakṣa karavīra, vāta, mallikā,* and *udumbara* are grown from the seeds and stalks (Borpuzari & Sarma, 2020).

4 Germination

After selecting the appropriate propagation method, the next stage is germination. Acārya explains various strategies for increasing germination capacity. Seeds derived from dried fruits that ripen naturally during the season, sprinkled with milk, and dried for five days. Then it was smoked with mustard seeds and *vidaṃga.* Cow dung*, bṛhati* powder, *tilā*, and *nāla* can also be used. Sugarcane-like plants are plastered with a mixture of honey, clarified butter, hog fat, and cow dung at the cut end. Smear the bulbous roots with honey and clarified butter. All seeds that have been handled and kept in this manner are safe to use. Classics also describe methods to promote the growth of inflorescences, stems, and foliage. One should first of all sow seeds in the seed bed, spread grasses over it, sprinkle milk and water, and then, when the seeds germinate, remove the grass, dry the earth a little, and transplant these sprouts together with their roots and the earth attached thereto (Ramchandra, 1993).

5 Plantation

Regarding the plantation, the *Bṛhatsaṃhitā* provides greater detail. When a sprout planted grows to one cubit in length, dig it out with the ground attached, apply *usira*, *vidaṃga*, and *ghee*, glued together to its roots, and then replant it in a pit with cow dung. The length, breadth, and depth of the pit are all the same as a forearm. If the garden level is plane, it's ideal to space the herbs at 2 cubits, bushes at 3, and trees at 4 cubits apart. If uneven, then trees are to be spaced 10 cubits in the lower level of the garden, 16 cubits in the middle level, and 20 cubits in the upper levels. The reason is that, even though the distance is not maintained, there is a chance of the roots of those plants interlinking, which may affect their growth. *Uttarāphālguna, Citrā, Mṛgaśīrṣa,*

Revatī, Mūla viśākhā, Tiṣya, Śravaṇa, Aśvinī and *Hasta* have been mentioned as favourable *nakṣatra* for seed sowing. When a tree is put under their impact, it will thrive. The trees with undeveloped branches and leaves should be planted in the months of *Māgha* and *Phālguna*. Plants with newly grown branches in the months of *Agrahāyaṇa* and *Pauṣa*, and well-developed branches in the months of *Śrāvaṇa* and *Bhadrā*. When small trees are one forearm tall, they should be transplanted during the day in the right direction. Honey, lotus fibre, ghee, and *vidaṃga* should be applied to the roots. During the nighttime, large trees should be transplanted with their roots covered. The canopy (*maṃḍapa*), quadrangular (*naṃdyāvarta*), *swastika*, square enclosing circle (*caturasra*), *sarvatobhadra, nikuñja*, and in clusters are all tree planting designs. Mist, storms, smoke, fire, and insects must all be avoided at all costs (Ankitha, 2022; Gupta, 2013).

6 Watering of plants

The rules for watering plants are also well outlined. Water well-rooted plants every alternate day in the winter, every evening in the spring, and three times a day in the summer. The ground linked to the roots of newly planted trees should be watered in the morning and evening. If the ditches have not dried up, overwatering causes indigestion (*ajīrṇā*), so do not pour fresh water in them. Plants with *ajīrṇā* are pale, leafless, infested with ants, have a fishy odour, and a deficit in bark. Based on soil, *jāṃgalā*: every morning and evening for 15 days, *sādhāraṇa*: morning and evening for 10 days, *anūpā*: once every 5 days (Kumar & Brijesh, 2023).

7 Nourishment of plants

Plant nutrition necessitates the use of manure. Organic farming is gaining popularity these days. Fungicides are recognized to effectively manage soil-borne illnesses in general and damping off in particular, but their widespread use has resulted in the creation of resistant plant pathogen strains, as well as the extinction of natural predators and parasites (Kumar and Brijesh, 2023). As a result, there is a need to alter existing circumstances and embrace new and distinct approaches. *Vṛkṣāyurveda* concepts are discussed here. Sprinkle ghee with cold milk, sesame, goat and sheep excreta, barley powder, and flesh of animals to encourage inflorescence and fruitification. It should be soaked in water for seven nights before being poured around the roots of plants. If the fruits of trees are destroyed, pouring cold water over them after they have been cooked with *kulattha, māśā, mudgā, yava,* and *tila* will result in the growth of flowers and fruits (Kumar & Jigeesh, 2024).

7.1 *Kunappājala*

The fermented liquid manure from organic wastes can be produced. *Kunappājala* was the most significant innovation, which was reportedly a first in world agri-history. *Kunappājala* is a natural organic product derived from animal and plant products that contains a significant amount of one or more primary nutrients such as nitrogen, phosphorus, and potassium, all of which are essential for plant growth. The literal meaning of *kunappā* is "smelling like a dead or stinking" (Shubhashree et al., 2018). Surapal's procedure involved collecting and storing animal waste as it became available. Surapal expanded the source of waste to include other animals, particularly those with horns, even though dead boar waste was listed first. *Kunappājala* could be made from almost any animal waste, giving farmers more options when it came to procuring their ingredients. To make *kunappājala*, boil the flesh, fat, and marrow of deer, pig, fish, sheep, and goat in water, then transfer the mixture to an earthen pot and add the compound milk, sesamum oil cake powders, honey, boiled *māṣaja* (pulse decoctions), clarified butter, and hot water. There is no set amount of any of these ingredients; however, when the pot is placed in a warm environment for about a fortnight, the combination transforms into *kunappā* (Ramchandra, 1993).

Blood, cottonseed, fish meal, and emulsion are good sources of nitrogen, whereas compost from bird manures, bone meal, and other sources of phosphorus and potassium help to regulate root, bud, flower and fruit formation, cell division, sugar formation in the sap, chlorophyll production and photosynthesis, and increase crop resistance to disease (Shubhashree et al., 2018). Some studies are ongoing nowadays regarding the effectiveness of *Kunappājala*. Along with *kunappājala, paṃcagavya* is gaining in popularity these days. *Paṃcagavya* is a combination of five cow-derived items. Cow dung, urine, milk, ghee, and curd are the ingredients. The first three are direct products, whereas the latter two are derivative products. *Gavya* is the brand name for all of these goods. It is utilized in seed germination, as a spray for nourishment, and to treat various diseases. For manufacturing *paṃcagavya*, fresh cow products such as cow dung (3 kg), cow urine (3 L), cow milk (2 L), curd (2 kg), and cow ghee (1 kg) were collected. The required quantities of five materials were thoroughly mixed in a container and fermented for seven days, stirred twice daily. In *paṃcagavya*, effective microorganisms are a mix of naturally occurring microbes, primarily lactic acid bacteria, yeast, actinomycetes, photosynthetic bacteria, and specific bacteria. *Paṃcagavya* contains chemolithotrophs and autotrophic nitrifiers, which proliferate on the leaves and boost ammonia intake and total N supply (Kumar and Brijesh, 2023). Individual treatments differed in efficacy, but *paṃcagavya* and *kunappājala* were shown to be the most

effective, with greater leaf nitrogen use, more efficient photosynthetic activity, and increased production. *Paṃcagavya* promotes soil fertility by enhancing macronutrients, micronutrients, and beneficial microbes, resulting in improved soil health. It improves soil water-holding capacity, increases plant nutrient uptake, and boosts plant growth. Earthworms, as well as their vermicast and body liquid (vermiwash), have been scientifically proven to be both growth promoters and plant defenders (Sinha and Mishra, 2013). To improve fruiting and flowering in various plants, different nourishing formulations were described in the classics (Ramchandra, 1993).

7.2 Plant protection

Vṛkṣāyurveda texts recommend fumigating plants with smoke from plant and animal materials to promote growth and control diseases. This practice, mentioned in 53 verses, suggests the presence of natural antimicrobials and growth promoters, such as karrikins. Drawing parallels with *Āyurvedika* smoke therapy in humans, the researchers highlighted the potential to validate and adapt these traditional methods for sustainable modern agriculture (Nene, 2014).

7.3 Plant diseases and treatment

The next step in the planting process is to safeguard them against infections and, if necessary, to treat them. Plants, like humans, are afflicted by diseases that are divided into two types: internal and external. Internal is caused by the *tridoṣa* in *Āyurveda*, which are *vāta*, *pitta*, and *kapha*. Its balance promotes health and has an imbalance effect in diseases, and the external one is influenced by insects, weather, and other factors. When a plant is infected with *vāta* diseases, it becomes slender and bent, with knots on the trunk or leaves, and hard fruits with less juice and flavour. When trees are overwatered with sweet, oily, sour, or cold substances in the winter and spring, *kapha* illnesses develop. Plants will take a long time to bear fruit, and the fruits will be pale, dwarfed, tasteless, and premature. *Pitta* kind of diseases occur at the end of summer when the clouds vanish, and the trees are overly flooded with pungent, sour, salty, hot, and intense things. Yellowness of leaves, premature fruit drop, and dryness, paleness of leaves, flowers, and fruits are the symptoms. When trees are exposed to heat or their roots are eaten away by insects, the leaves dry out, turn yellow, become excessively pale, and lose their natural aroma. Fire, wind, continual shade, bird overcrowding, excessive creeper growth, and weed growth are all factors that kill trees. *Vāta* diseases can be healed with flesh, marrow, and ghee. *Kunappājala* can also be used. Using bitter, astringent decoctions of *bṛhat paňcamūla (vilw, kashmāri, tarkāri, pātal, dunduk*), coating the roots with white mustard paste, watering with a sesame and ash mixture, and removing the soil around the plant and replacing it with new soil can treat kapha diseases. *Pitta* disorders can be healed by consuming cool and sweet foods. Watering with milk, honey, *yaṣṭimadhu,* and *madhuka* decoctions (Panchaware et al., 2023; Rananavare & Chitnis, 2024).

Triphalā, ghee, and honey can also be used. To cure the plants, scrape off the damaged areas with a knife, and then apply mud kneaded with ghee and *vidaṃga* to the affected areas, followed by a round of milk diluted with water poured around the roots. A hot decoction of *kulattha, māśa, mudgā, tila,* and *yava* should be prepared for the treatment of bareness and sprinkled around the roots once cooled. Different kinds of insecticides were mentioned here. Watering a plant with cold water for seven days will help to ward off insects from the roots and branches. Paste made up of *kuṣṭha, sarṣapa, vāca,* and *ativiṣa* can be applied externally for worm infestations. Smoking (*dhupanā*) tree with *saraśapa, hiṃgu, vidaṃga, vāca, uṣṇa, bhallātaka*, flesh of animals and birds. If a wound caused by insects is present on plants, apply a paste of *viḍaṃga, gomūtra, ghī*, and *saraśapa*, then sprinkle with milk. *Nyagrodha, udumbara*, *ghī*, and honey paste can also be anointed for wound healing. For a burnt tree, the treatment is to sprinkle water and milk, then smoke it with crab shells. Then fresh sprouts will develop. Treatment for plants struck by lightning and thunder is also well explained in the classics. Anoint the plant with *a mixture of vidārī (Pueraria tuberosa), sugar, nāgajihvā (Anicostema axillare), and tila*, then sprinkle with milk water. Many treatment protocols and various dosage forms were explained very well in classics (De Silva, 2024).

7.4 Horticultural wonders

Botanical marvels, often known as horticultural wonders, are a fascinating topic in agricultural studies. They produce flowers on creepers, transform trees into creepers and dwarf trees, promote longevity of ripeness and non-ripening, prolong the longevity of the crop, promote destruction and quick rejuvenation, quick production of fruits, increase the size of fruits and flowers at the very appearance, and transformation into another species. This botanical wonder can be linked to plant breeding. Plant breeding is the science of altering plant traits to produce desired characteristics. For a month, trees watered at the base with buttermilk, sugarcane juice combined with *gomāṃsā kurnā, vidaṃga,* and *oil* cakes also *vārāhī, jīrā*, and sugarcane juice should be preserved for a month in a pot with ghee made in the moonlight, and when the mixture is well formed, it should be smeared on the tree roots and the basin filled with mud by these plants will produce gorgeous blossoms and fruits that are out of season. If a tree that normally produces pungent fruits is liberally smeared at the base with a paste made

of *vidaṃga, yaṣṭi, yava*, milk, and jaggery, it will produce sweet nectar-like fruits. If a tree's chopped stem is covered with boiled sugarcane juice and sugarcane juice is applied to its roots, it will produce blossoms out of season (Chaturvedi & Chaturvedi, 2017). When sugar, *yaṣṭimadhu, kuṣṭha,* and *madhukā* flowers are pasted together and placed at a tree's root, it produces fruits without seeds. Parthenocarpy is a method of producing fruits without seeds. If a tree is sprayed with *kulathā,* or a decoction consisting of *palāśa, arjuna,* and *tārakārī*, mixed with salt, it will lose its fruits and blooms. When a tree is planted in a pit dug in the earth with bricks all around, 4 1/2 cubits deep, it always remains dwarfish and bears blossoms and fruits. Dwarfing can be considered a good trait in gardening. Selective breeding, genetic engineering, or grafting onto dwarfing rootstocks can all be used to achieve this type of dwarfing. Dwarfing helps produce trees in small spaces quickly, which is advantageous for cultivation methods (Praphulla, 2005; Ramchandra, 1993).

8 Scientific validation

Classic *Vṛkṣāyurveda* texts address a wide range of significant topics. Many of the subjects covered in this article are likely to interest many researchers. Cultivators have used these organic growing methods for ages. The moment has come to reevaluate and put into practice natural methods that help avert numerous diseases. Due to the presence of heavy metals, chemicals from waste disposal, various pesticides, and fertilisers, collecting herbal remedies from untamed areas may cause harmful effects on the body as demand for these medicines rises (Ramachanran, 1984). This will render the treatments undertaken with these medicines futile, thereby indirectly affecting the dignity of science (Jeerankalagi, 2022). So, the techniques explained here can be adopted for the cultivation of various medicinal plants, focusing on the healthy production of new saplings within a short time without losing their inherent potential.

8.1 Seed germination

A study on *Embelia* evaluated pre-germination treatments on fresh and stored seeds of *Embelia ribes* using *Vṛkṣāyurveda* methods. Seeds soaked in cow dung slurry showed the highest germination (83.33% fresh, 43.33% stored) compared to controls. Results indicate that *E. ribes* seed viability, despite being recalcitrant, can be preserved up to three months using low-temperature or earthen pot storage with appropriate pre-treatment (Raghu et al., 2016). *Bākucī* (*Psoralea corylifolia*) seeds face germination challenges due to hard seed coats and low viability. Among various treatments, the group using a *Vṛkṣāyurveda*-based paste showed the best germination results, outperforming control and acid-treated groups. This traditional method offers a promising, safer alternative for propagating this endangered medicinal plant (Aralelimath et al., 2016). A study on chickpea seed germination showed that 10% *Vṛkṣāyurveda*-based *kunappājala* priming significantly improved germination rate, seedling vigor, water uptake, α-amylase activity, and growth parameters. Results were comparable to hydropriming, making 10% *kunappājala* an effective seed invigoration treatment for enhancing chickpea seed performance and early seedling development (Halder, 2021).

Aśoka (*Saraca asoca*), vital in Āyurvedic gynaecological treatments, is endangered due to overharvesting and a lack of cultivation. In a study based on *Vṛkṣāyurveda*, seeds of *Aśoka* and *Gambhārī*, soaked in milk, rubbed with cow dung, and smeared with honey and *vidaṃga*, showed the highest and statistically significant germination percentage. These seeds also produced plants with higher *Aśoka* and *Gambhārī* content than acid-treated controls, confirming the efficacy and safety of traditional methods (Vashist, 2018). In contrast, a study comparing the conventional method, H_2SO_4, and *Vṛkṣāyurveda* methods found that conventional treatment had the highest germination rate (38%), while *Vṛkṣāyurveda* was least effective, suggesting that further research into its methodology is needed (Prachi & Pramod, 2016).

8.2 Plant nourishment

Sinha and Mishra (2013) investigated the use of *Brassica alba* as a biofertilizer and found enhanced growth and yield in paddy. Compared with urea alone, combining B. alba liquid manure with blue-green algae significantly improved plant height, inflorescence length, grain yield, and seed quality, demonstrating B. alba's effectiveness in boosting crop productivity sustainably. A field experiment at Karuṇya Institute, Coimbatore, explored eco-friendly *Vrikshāyurvedika* farming in green gram using green leaf manures and tree leaf extracts. Among nine treatments, *Pongamia pinnata* as manure and *Moringa oleifera* foliar spray yielded the highest output (952 kg/ha), net return (Rs. 39,647/ha), and benefit–cost ratio (1:2.25), highlighting the sustainability and economic viability of traditional organic farming practices in pulses (Dhivyalakshmi et al., 2023). Tamil Nadu Agriculture University, Madurai (2020–21) evaluated proso millet performance under *Vṛkṣāyurveda*, conventional, and no-input practices. Biomass Transfer from *Albizia lebbek* and *Gliricidia sepium*, and 5% Leaf Tea Spray from *Mangifera indica* and *Moringa oleifera*, produced agrochemical-free grains with under 10% yield reduction compared to conventional methods, proving *Vṛkṣāyurveda's* effectiveness (Chitraputhirapillai et al., 2024).

8.3 Studies on *kunappājala*

Mishra (2007) tested the effect of *kunappājala* upon paddy. Various parameters, including plant height, leaf length, leaf number, and inflorescence length, were evaluated in the test culture receiving *kunappājala* at different time intervals. Administration of *kunappājala* every 10 and 15 days, significantly increased the growth parameters: plant height, leaf, and inflorescence length. Ankad et al. (2021) conducted a study evaluating the effects of two traditional Indian treatments, *kunappājala* (KJ) and *paṃcagavya* (PG), on the growth and production of diterpenoids in the medicinal plant *Andrographis paniculata*. The experiment was conducted in a randomised block design with six treatments: control, KJ, PG, farmyard manure, inorganic fertiliser, and humic acid. The results showed that KJ produced higher leaf area and leaf area index at 90 days after sowing (DAS), and higher leaf area duration between 90 and 120 DAS. PG produced a higher crop growth rate, relative growth rate, and net assimilation rate between 60 and 90 DAS. The RP-UFLC analysis revealed that PG treatment resulted in the highest levels of the three diterpenoids (A1, A2, and A3) at 120 DAS. The study concluded that *kunappājala* and *paṃcagavya* treatments were better or at par with respect to physiological parameters and diterpene production in *Andrographis paniculata*.

A field study at GBPUAT, Pantnagar (2020–21) tested *Vṛkṣāyurveda*-based *kunappājala* on *Matricaria chamomilla*. Nettle-based *kunappājala* (T3) showed promising results—early flowering, larger flower diameter, highest essential oil content (0.27%), and 33 bioactive compounds—comparable to chemical fertilizers (RDF). *Kunappājala* improved nutrient availability and antioxidant potential, suggesting its sustainable use, though further multi-season validation is needed (Kalpasi, 2021). Naik (2022) conducted a field experiment over two *rabi* seasons (2020–21 and 2021–22) at the Norman E Borlaug Crop Research Centre of GBPUAT, Pantnagar, to study the impact of *Vṛkṣāyurveda-based* liquid fermented organic manure (*kunappājala*) formulations and their doses on mustard productivity and soil health. The experiment used a factorial randomised block design with three types of herbal kunappājala concoctions (nettle grass-based, common weed-based, and a 50–50 mix) and four doses (500, 1000, 1500, and 2000 l/ha). The results showed that plant height, dry matter accumulation, number of branches, total chlorophyll, carotenoid, SPAD, and NDVI were significantly higher in the KJ1 (nettle grass-based) and D4 (2000 l/ha) treatments than in the control. Yield-attributing characters, crop yields, protein and oil content, and economics were also higher in the KJ1 and D4 treatments. The rest treatment (herbal *kunappājala*) showed better soil properties compared to the control treatment.

Herbal *kunappājala*, a bioformulation revived by the Asian Agri-History Foundation from Surapala's *Vṛkṣāyurveda*, has proven effective in organic farming. Used on crops like tomato, brinjal, okra, and chillies, it enhances plant growth, fruiting, and nutritional value. In tomatoes, it improves lycopene content, taste, appearance, and shelf life, benefiting transportation and market appeal (Beniwal, 2023). *Aśvagaṃdhā* (*Withania somnifera*), a key herb in *Āyurveda*, is known for its diverse therapeutic uses. Its cultivation can be enhanced through *Vṛkṣāyurveda*, especially *kunappājala*, an ancient organic fertiliser, integrating traditional practices with scientific insights for holistic, sustainable use (Kumar & Sharma, 2024). (Table 1).

A study on low-budget natural farming using *Vṛkṣāyurveda* methods involved green leaf manures and leaf-tea nutrition for plant growth and protection. Compared to conventional farming, yield reduction ranged from 2.16 to 46.7% across crops. However, the chemical-free produce offers potential for premium pricing, compensating for lower yields and supporting sustainable agriculture practices (Swaminathan, 2021).

9 Limitations

- Scientific validation: Farmers and policymakers demand quantitative evidence. Traditional formulations often lack standardised recipes or rigorous trials.
- Regulatory uncertainties: Differing organic certification rules across countries create confusion, particularly regarding animal by-products.
- Resource constraints: Access to Indian desi cows, mulch materials, or specific ingredients limits adoption in some regions.
- Skill requirements: Farmers lack the required skills to implement *Vrikshāyurvedika* solutions in their field.

10 Government initiatives on sustainable farming

India provides some of the strongest policy support for *Vrikshayurvedic* analogues. The state of Andhra Pradesh spearheads the Zero-Budget Natural Farming (ZBNF) programme. By 2024, the programme covered 409 000 ha across eight states, with 12% of Andhra Pradesh's farmers practising ZBNF (Duddigan et al., 2024). The state set a goal of reaching 6 million farmers and provides training, credit support, and marketing assistance through the Rythu Sadhikara Samstha. The NITI Aayog's compilation of success stories highlights national recognition and dissemination through Krishi Vigyan Kendras (farm science centres) (NITI Aayog, 2022).

Table 1 A comparison of *Vrikshāyurvedika* practices with their scientific validation

Plant processes	*Vrikshāyurvedika* practices		Scientific validation	
	Method	Plants	Plants	References
Seed sowing and germination	Pre-treatment of seeds with milk, clarified butter for 5 days, sun dry	*Jambula* (*Syzygium cumini*), *Panasa* (*Artocarpus heterophyllus*), *Āmrātaka- Spondias pinnata*, *Sarala* (*Pinus longifolia*), *Lakuca* (*Artocarpus lacucha*)	*Embelia ribes*	Praphulla, (2005)
			Bākucī (*Psoralea corylifolia*)	Aralelimath (2016)
	Mix with cow dung, sesamum ash, *vidaṃga, bṛhati*, honey, and dry in sun		Chickpea	Halder, (2021)
			Aśoka (*Saraca asoca)*	Prachi & Pramod, (2016)
			Aśoka and *Gambhārī*	Vashist, (2018)
Plant nourishment	Powdered oilcake of mustard/sesamum	*Khajūra, Bilva, Lakucā*	Paddy	Sinha and Mishra (2013)
	Husk soaked water, leaves of *Pīpala, Vaṭa, Palākṣa, Āmra*	*Āmra*	Greengram Proso millet	Dhivyalakshmi et al., (2023) Chitraputhirapillai et al., (2024)
	Milk of deer, boar, jackal, elephant, horse	*Yajñadruma*		
	paddy washing water	*Niculapatra*		
	Pulse decoction	*Amalākā*		
	Water and Milk	*Tiṃdukā*		
	Barley powder	*Nāriyala*		
	Ghee, *kunappā* water, *vāca*, pig's stool's decoction of water with *kulattha* powder	*Dāḍimā*		
Kunappājal	General plant growth tonic		Paddy	Mishra (2007)
			Andrographis paniculata	Ankad et al (2021)
			Matricaria chamomilla	Kalpasi, 2021
			Rabi Crops	Naik (2022)
			tomato, brinjal, okra, and chillies	Beniwal (2023)
			Ashwagandha	Kumar & Sharma, 2024

Such institutional backing lowers financial risk and enhances credibility among farmers.

Other countries have implemented parallel policies. South Korea's promotion of Korean Natural Farming (KNF), a system that cultures indigenous microorganisms and recycles farm waste, has gained popularity across Asia and Hawai (Keliikuli, 2018). Local governments and NGOs provide training and certification, although scientific evidence remains limited. These examples show that state support and farmer networks are crucial for scaling community-based biofertiliser systems. A comparison of these methods with Vrikshayurvedic and modern is shown in Table 2.

10.1 Recommendations for scaling up *Vṛkṣāyurvedika* solutions globally

10.1.1 Scientific validation and standardization

Governments and research institutions should conduct multi-location, multi-season trials to quantify yields, nutrient dynamics, and environmental impacts of Kunappājala and Pañcagavya. Developing standardised guidelines for preparation and application will help certification agencies and farmers.

10.1.2 Policy integration

Organic standards should explicitly address fermented animal- and plant-based biofertilisers, providing clear rules on acceptable ingredients and composting requirements. Policies that encourage on-farm composting, support indigenous livestock breeds, and fund farmer-to-farmer training can facilitate adoption.

10.1.3 Scaling production and distribution

Cooperative units or small enterprises can produce ready-made bioformulations, reducing labour burdens. Public–private partnerships could ensure quality control and supply chain management while keeping costs low.

Table 2 Comparison of vrikshāyurvedika inputs with other organic and conventional approaches

Aspect	Vṛkṣāyurvedika inputs (*kuṇapajala/pañcagavya)*	Organic approaches (farmyard manure, compost, ZBNF, KNF)	Conventional chemical fertilisers
Main ingredients	Fermented mixtures of cow dung/urine, milk products, oil cakes, legumes; Kunappājalamay include animal flesh or bones	Compost, vermicompost, humic acids; ZBNF uses cow dung/urine, jaggery, legume flour; KNF uses indigenous plants and microorganisms	Synthetic NPK compounds produced from minerals and fossil fuels
Nutrient profile	High N, K, Ca, Mg and micronutrients in Kuṇapajala; Pañcagavya has moderate N and higher P	Variable; compost and FYM contain lower nutrient concentrations; Jīvāmṛt acts mainly as microbial inoculum	Precise and high nutrient concentrations; immediate availability
Soil health impact	Enhances soil organic carbon, nutrient availability and enzyme activitiesactabotanica.org; enriches microbial diversity; improves seedling vigour	Mulching and microbial inoculants in ZBNF/KNF promote moisture retention and beneficial microbes	May degrade soil structure and reduce microbial diversity when overused
Yield performance	Comparable to organic controls; sometimes close to chemical fertilisers but often slightly lowerpmc.ncbi.nlm.nih.gov. Field cases show higher yields and profitability than conventional farming due to reduced costs	ZBNF trials show no yield penalty and sometimes higher yields KNF experiments increased yields	High yields but can cause long-term soil degradation and require continued purchase
Cost and labour	Low input costs but labour-intensive to prepare	Composting may require space; ZBNF inputs are cheap but require labour and cow availability; KNF uses local materials	High cost of fertilisers; minimal labour
Regulatory acceptance	Uncertain; animal flesh components face restrictions in EU and require composting in US	Generally accepted if composted properly; some inputs like jaggery or bran are universally permitted	Widely accepted but subject to nutrient runoff regulations

10.1.4 Capacity building

Extension services must train farmers in fermentation techniques, bio-safety, and integrated pest management. Incorporating traditional agricultural knowledge into curricula and supporting research centres will preserve and modernise Vrikshāyurvedika wisdom.

10.1.5 International collaboration

Comparing Vrikshāyurvedika practices with other natural farming systems (e.g., ZBNF, KNF) can foster cross-cultural learning. Exchange programmes and joint research can help adapt these techniques to diverse ecosystems and regulatory environments.

11 Future research directions

A few areas that need to be explored for efficient implementation of *Vṛkṣāyurvedika* methods are as follows;

- Phytochemical characterization of *Vṛkṣāyurvedic* formulations (e.g., *Kunapājala* and *Pañcagavya*) to identify active compounds influencing plant growth, pest control, and soil microbiota.
- Comparative trials under controlled and field conditions to quantify yield, disease resistance, and nutrient uptake relative to standard organic and conventional practices.
- Standardization protocols for preparation, dosage, and application frequency to ensure consistency and reproducibility across regions and crop types.
- Development of scientific metrics to measure "bioefficacy" and "eco-synergy" of *Vṛkṣāyurvedika* inputs using metabolomics, metagenomics, and soil microbiome analyses.

12 Conclusion

The use of herbal drugs as medicine in *Āyurveda* and other allied sciences is gaining acceptance worldwide nowadays. People from other nations are also expressing an interest in the ideologies and underlying concepts of these sciences. We must therefore make things more precise and authentic. The existence of these sciences would be questioned without the use of herbal remedies. Growing medicinal plants is an area we need to focus on. The use of modern equipment, methodologies, and the obscure concepts revealed in the classics will aid in raising the standard of agriculture, paving the way for widespread acceptance. Also, proper interpretation of the ideas in *Vṛkṣāyurveda* will help build an eco-friendly environment that benefits all living beings in nature.

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