Review Article

Application of *Panchagavya*, a Cow-based Liquid Formulation, as a Lever for Sustainable and Enhanced Vegetable Crop Production: A Review

ABSTRACT

Panchagavya, a fermented liquid bio-formulation derived from cow-based products such as dung, urine, milk, curd and ghee, has recently gained importance in agricultural practices due to its reported effectiveness in enhancing vegetable crop production. Its formulation involves a fermentation process that harnesses the diverse microbial communities present in cow-derived substances, resulting in a potent nutrient-rich solution that is believed to possess plant growth-promoting properties. One of the primary mechanisms underlying its efficacy lies in the diverse array of microorganisms present in the formulation. These microorganisms, including beneficial bacteria, fungi and actinomycetes, play crucial roles in nutrient cycling, disease suppression and soil conditioning. Additionally, *Panchagavya* contains plant growth-promoting substances such as hormones, enzymes, vitamins and amino acids, which contribute to enhanced nutrient uptake, root development and overall plant vigour. Furthermore, application of *Panchagavya* has been shown to improve soil health by enhancing microbial activity, increasing organic matter content and improving soil properties. These soil improvements not only benefit the current crop but also have long-term positive implications for soil fertility and sustainability. This multifaceted approach to crop management offers a holistic solution to enhance crop productivity while reducing reliance on synthetic inputs. This review aims to comprehensively analyse the literature on the effects of *Panchagavya* on vegetable crops, highlighting its mechanisms of action and potential benefits for increased vegetable crop production.

Keywords: Panchagavya; liquid manure; vegetable; crop production; soil health; sustainability

1. INTRODUCTION

The increasing emphasis on global food security and sustainable agricultural practices has highlighted intensive vegetable cultivation, marked by high multiple cropping indices and significant yields in compact areas [1,2]. However, because of extensive use of nitrogenous fertilisers and frequent irrigation requirements, this method raises concerns regarding long-term soil health and environmental degradation [3]. Excessive input of chemical fertilisers has led to serious human health hazards and environmental threats, such as soil erosion, water pollution, pesticide poisoning, declining groundwater table and depletion of biodiversity [4]. These concerns point to the necessity of researching organic fertilisers (manures), which can potentially improve the soil characteristics and boost crop productivity, while minimising environmental pollution [5]. In addition to organic manures, traditional organic formulations, such as *Panchagavya*, are being adopted and used to enhance soil fertility and productivity in recent times [6].

India is a land of traditions with its roots embedded in ancient science that directly links social rituals and the scientific reasons behind them [7]. In India, the cow is worshipped as '*Gomata*' or '*Kamadhenu*' due to its nourishing nature like a mother, and farmers are emotionally attached to cows [8,9]. There are a lot of benefits from the cow that have been demonstrated in relevance of environment and agriculture [10]. '*Panchagavya*' has been derived from two words, '*panch*' meaning five and '*gavya*' meaning obtained from '*gau*' or cow [11], which *in toto* represents five products obtained from a cow, namely dung, urine, milk, curd and ghee (clarified butter). Each *gavya* possesses different components and uses for agriculture. The concept of *Panchagavya* stands as a testament to the harmonious relationship between humans, livestock and nature [12]. *Panchagavya* has got reference in *Ayurveda* and *Vrikshayurveda*, the life sciences of the Vedic period, which glorify cow as the symbol of life-giving sustenance and highlight its role as a provider of nourishment and resources. It plays a crucial role in organic farming practices as an organic manure for agricultural fields. *Panchagavya*, as a mixture of these quintessential cow products, is believed to possess characteristic properties that can enrich soil and promote plant growth. Its application ensures zero usage of harmful synthetic fertilisers, insecticides, pesticides and antibiotics.

In countries with a predominantly vegetarian population, such as India, vegetables are an important part of the daily diet. With increasing public awareness of the negative impacts of indiscriminate use of agrochemicals in crop and soil productivity, the significance of vegetables as indispensable components of nutritional security for healthy sources of essential nutrients, vitamins and minerals is also growing. This has led to an increased demand for organically-grown vegetables because they are devoid of any toxins that could be dangerous to human health [4]. Consequently, a growing number of vegetable growers are switching to organic farming. In this scenario, finding new organic manures that are economical and environmentally safe is crucial. To the best of our knowledge, the information on the effects of traditional organic formulations, like *Panchagavya*, on the growth, yield, quality, disease and pest resistance, and economics of vegetable crops for achieving sustainable and increased production is still lacking. Therefore, the present review has been written with an aim to highlight the salient characteristics of *Panchagavya*, describing its composition, preparation, characterisation and methods of application, along with its effects on various parameters of vegetable crops, all of which are well-supported by the existing scientific evidences. It also focuses on the challenges and limitations of the application of *Panchagavya*, and some research needs that need to be addressed in future.

2. COMPOSITION, PREPARATION AND CHARACTERISATION OF *PANCHAGAVYA*

2.1 Components of *Panchagavya*

Cow-based products are the basic components of *Panchagavya*, while some plant-based products are used to increase its efficacy (Fig. 1). Given below are the components of *Panchagavya* and their remarkable properties:

2.1.1 Cow dung (Gau-maya)

The use of cow dung for dressing seeds, plastering cut-ends of vegetative propagating structures, dressing wounds, sprinkling as a diluted suspension on plants and applying to soil has been reported by Nene [13]. Cow dung is an inexpensive and easily available source of microflora. It hosts a diverse group of microorganisms, containing different species of bacteria (e.g., *Bacillus* spp., *Lactobacillus* spp. etc.), protozoa and yeast (e.g., *Saccharomyces*) [13,14]. It also contains majority of the essential plant nutrients like nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, iron, copper, zinc, cobalt and manganese. According to Vedic literatures, the dung procured from indigenous Indian cows has higher amounts of minerals than the cross-bred [14,15].

2.1.2 Cow urine (Gau-mutra or Gau-jala)

The use of cow urine in agriculture to improve crop growth and yield has been documented since ancient times. It is rich in nitrogen, potassium and phosphorus, and therefore, beneficial to soil either when diluted and directly applied, or when indirectly applied as formulations. The presence of sulphur, sodium, manganese, iron, chlorine and enzymes makes cow urine a potent and low-cost natural pest repellent [16]. Cow urine contains 95% water and 2.5% urea, and the remaining 2.5% comprises a mixture of salts, minerals, hormones and enzymes [17]. Cow urine finds use in agricultural operations as a biofertiliser, bioenhancer and biopesticide [11,18], and is a major component of organic farming [9].

2.1.3 Cow milk (Gau-dugdha)

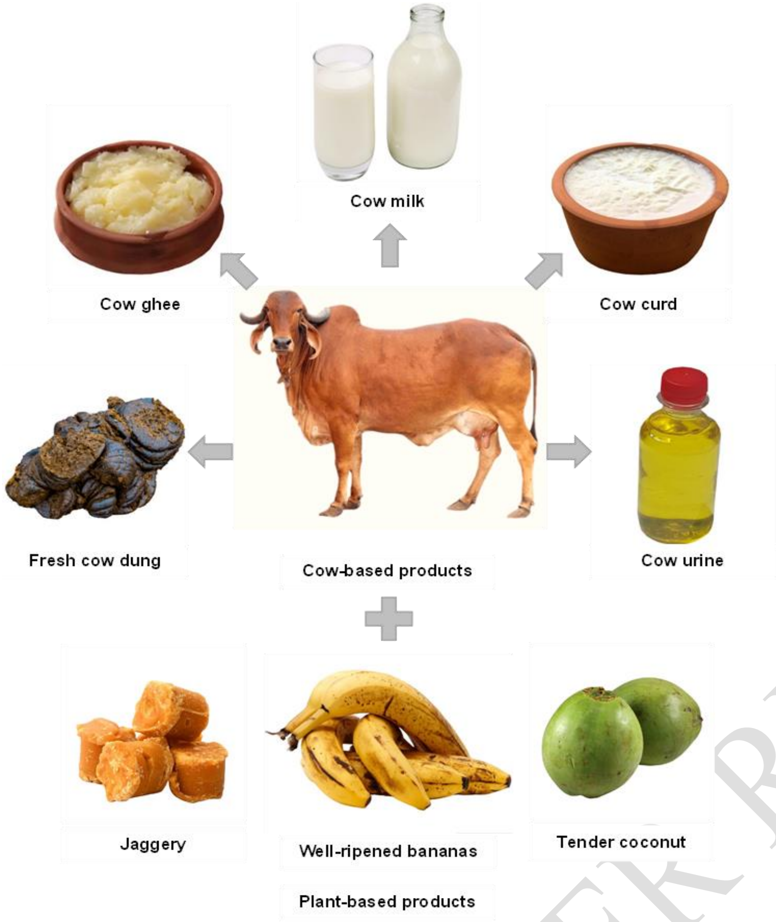

Fig. 1. Ingredients of *Panchagavya*

Cow milk is an excellent source of nutrients, viz. proteins, fats and carbohydrates, lactose, essential amino acids, minerals like calcium and phosphorus and *Lactobacillus* bacterium, which are helpful in boosting the growth and multiplication of beneficial microorganisms in *Panchagavya* [19]. Glutamic acid, leucine and proline make up about 40% of the total amino acids in cow milk, and high amounts of endogenous proline encourage auxins and cytokinins in plants to induce systemic resistance [13,20]. Spraying of raw milk has been reported by Kumar et al. [21] to induce systemically acquired resistance (SAR) in chilli against leaf-curl, a viral disease. Similarly, 10% aqueous suspension of milk has been proven effective in controlling powdery mildews. Besides, cow milk has exceptional sticking and spreading qualities.

2.1.4 Cow ghee (Gau-ghrita)

There are records of cow ghee being used in the ancient and medieval times for managing seed health [22]. Cow ghee (clarified butter) contains vitamin A, vitamin B, calcium, fats and glycosides which protect and help in better recovery of the cut plant portions or wounds from infection [13].

2.1.5 Cow curd (Gau-dadhi)

Cow curd is rich in *Lactobacillus*, which promotes fermentation [23] and acts as a catalyst in the digestion of organic wastes [24]. This contributes to the soil microbial diversity and improves soil health.

2.1.6 Jaggery, bananas and tender coconut water

Apart from the above five cow-based products, *Panchagavya* also contains some additional components, viz. jaggery or sugarcane juice, bananas and tender coconut water. Jaggery (or sugarcane juice, if jaggery contains some chemical ingredients) and coconut water are reported to accelerate fermentation. Coconut water is a cheaper substitute for kinetin [25], a cytokinin, which activates the meristem growth at a faster rate. Jaggery contains potassium, which helps improve soil fertility as well as increases disease resistance in plants [26]. Banana, being a rich source of carbohydrates, vitamins and minerals, serves as substrate for the microorganisms. Thus, jaggery or sugarcane juice, bananas and tender coconut water, when added to the mixture of cow-based components, act as fermenters and increase the nutrient concentration and microbial population in *Panchagavya*.

2.2 Preparation of *Panchagavya*

The most recent and widely used formulation of *Panchagavya*, suited to various field and horticultural crops, has been standardised as given in Table 1.

Table 1: Ingredients used in preparation of *Panchagavya* [27]

Sl. No.	Ingredients	Quantity
1.	Cow dung (Fresh)	5 kg
2.	Cow urine (Fresh)	3 L
3.	Cow milk	2 L
4.	Cow curd	2 L
5.	Cow ghee	1 kg

6.	Jaggery	500 g dissolved in 3 L water
7.	Bananas (Well-ripened)	1 dozen (=12 bananas)
8.	Tender coconut water	2 L
9.	Water	10 L

For preparing *Panchagavya*, a wide-mouthed mud container, plastic container or concrete tank can be used, but metal container should be avoided. First, the cow dung and cow ghee are mixed in the container. The mixture is stirred thoroughly in clockwise and anticlockwise directions, twice daily, for three days. On the fourth day, rest of the ingredients are added, and the mixture is stirred thoroughly in clockwise and anticlockwise directions, twice daily, for 15 days. The *Panchagavya* stock solution will be ready by the 18^{th} day. The container should be kept in the shade with its mouth covered with a wire mesh or plastic mosquito net to prevent houseflies from laying eggs. If jaggery is not available, then 3 L of sugarcane juice can be added.

By using the quantity of ingredients specified in Table 1, one can obtain approximately 20 L of Panchgavya with the cost of production of around Rs. 25 L^{-1}. However, if the volume is more and the farmers use their own cow's products, the cost can be further reduced.

2.3 Characterisation of *Panchagavya*

2.3.1 Physico-chemical characteristics

The physico-chemical properties of *Panchagavya* are given in Table 2. The physical characteristics of *Panchagavya* largely depend on the inner makeup of the product. The carbohydrates, proteins and lipids present in the components of *Panchagavya* produce volatile fatty acids, volatile amines, methane etc. during fermentation [28], which induce the change in odour of the formulation from foul to fruity. Sometimes, mold growth may be observed on the surface of the formulation during storage due to the presence of undecomposed solids [29].

The low pH of *Panchagavya* is due to fermentation and the presence of *Lactobacillus* bacteria, which converts sugars into organic acids, such as lactic acid [30], while higher EC might be attributed to the increase in soluble salts [27]. Besides these, *Panchagavya* contains a substantial amount of both macro and micronutrients as a result of microbial decomposition of the organically bound forms of these elements.

2.3.2 Microbial population dynamics

Cow dung, milk and curd are active ingredients of *Panchagavya*, and are rich sources of beneficial microbes, such as *Lactobacillus* spp. [33,34]. The nutrient richness of the mixture obtained from ingredients of cow origin, viz. cow milk, curd and ghee, might be the reason behind the large microbial population, especially of bacteria, in *Panchagavya*. Chemolithotrophs and autotrophic ammonifiers and nitrifiers are also present in *Panchagavya*, which are reported to increase the ammonia uptake, thereby increasing the total nitrogen supply [24]. The naturally occurring beneficial microorganisms, such as *Lactobacillus*, *Saccharomyces* (yeast), *Streptomyces*, *Rhodopseudomonas* and *Aspergillus*, constitute the effective microorganisms (EMOs) in *Panchagavya* [35,36]. Besides these, *Panchagavya* also harbours a significant population of fungi, actinomycetes, *Pseudomonas*, *Rhizobium*, *Azotobacter*, *Azospirillum* and P-solubilising microbes [37].

Table 2: Physico-chemical properties of *Panchagavya* [29,31,32]

Particulars	Characteristic nature/Value
Colour	Light/Tortilla brown
Odour	Pleasant/Fruity smell
Touch	Dense liquid
pH	5.32
Electrical conductivity (dS m^{-1})	8.46
Organic carbon (%)	0.861
N (%)	2.40
P_2O_5 (%)	0.062
K_2O (%)	0.413
Ca (ppm)	990
Mg (ppm)	130.40
S (ppm)	160
Fe (ppm)	77
Mn (ppm)	6

Zn (ppm)	26
Cu (ppm)	67

2.3.3 Biochemical properties

Many metabolites have been identified in *Panchagavya* belonging to various classes, viz. benzene and substituted derivatives, carboxylic acids and derivatives, fatty acyls, nucleosides, nucleotides, pyridines and derivatives, steroids and derivates etc., through GC-MS/MS (Gas chromatography-mass spectrometry) analysis [29].

Benzoic acids are important structural elements for numerous metabolites like plant hormones, cofactors, defense compounds etc. [38]. Niacin gets converted into NAD+ or NADP+ in the plant cell and is directly involved in photosynthesis and fatty acid metabolism [39]. Gibberellic acid stimulates seed germination, promotes internode elongation and regulates sex expression (maleness) [40]. Ascorbic acid and rhodophin, a carotenoid, act as antioxidants, and are involved in singlet-oxygen quenching and free radical-scavenging activities [41,42]. Similarly, phenylacetic acid, cinnamic acid, chlorogenic acid and *p*-coumaric acid are reported to show anti-fungal properties [43,44].

3. METHODS AND DOSAGES OF APPLICATION OF *PANCHAGAVYA*

Panchagavya is considered a highly effective liquid organic manure, and should be used for agricultural purposes only after diluting with water. Following are some of the commonly used methods of application of *Panchagavya*:

3.1 Foliar spray

One of the most common methods of application of *Panchagavya* is foliar spray. A 3% solution (3 L of *Panchagavya* in 100 L of water) is ideal for all crops [45] and is found to be more effective compared to higher and lower concentrations. Spraying of *Panchagavya* solution directly on to the foliage allows for immediate absorption of nutrients. This method strengthens plant immunity and control insect-pests and fungal diseases like anthracnose and powdery mildew.

3.2 Irrigation

Panchagavya solution can be mixed with irrigation water @ 50 L ha^{-1} (≈20 L $acre^{-1}$) and made available to the plants either through flow irrigation or drip irrigation (fertigation).

3.3 Soil drenching

Soil drenching involves pouring diluted *Panchagavya* solution directly into the soil around the base of the plants so as to feed the roots and soil microbiome. It supplies nutrients directly to the roots, improves soil physical properties such as structure and aeration, and feeds the beneficial soil microorganisms. Soil drenching with *Panchagavya* supplies micronutrients that have been used up over time, and thus, helps remineralise the soil. Usually a 3% solution is ideal for all crops, however, the dosage may be increased up to 10% depending on plant need.

3.4 As seed/seedling treatment

Seeds, tubers and seedlings can be soaked or dipped in a 3% solution of *Panchagavya*, for about 30 minutes, prior to sowing/planting. Panchagavya is rich in nutrients and growth hormones, and soaking seeds in this solution induces early germination and produces vigorous seedlings [46].

3.5 For seed storge

Seeds may be dipped in a 3% solution of *Panchagavya* before drying and storing them.

4. EFFECT OF *PANCHAGAVYA* ON VARIOUS PARAMETERS

4.1 Effect on growth parameters

In *Spinacea oleracea*, Sailaja et al. [47] recorded increase in total biomass (301.92%), shoot length (88.53%) and root length (71.03%) in *Panchagavya*-treated plots over control (water spray). *Panchagavya* produced bigger leaves and denser canopy in the plants, leading to enhanced photosynthetic efficiency and synthesis of maximum metabolites. Sarkar et al. [48] observed maximum significant and positive response with regards to node number enhancement (as high as 67.24% in cowpea and 60.16% in chilli) with the application of 3% *Panchagavya* as soil drenching. Ponnumani and Semmalar [49] studied the effect of different concentrations (25%, 50%, 75% and 100%) of *Panchagavya* on growth parameters of *Capsicum frutescens* and concluded that plant height, leaf length, leaf weight and root length showed gradual positive response with increase in the concentration of *Panchagavya*. Rao et al. [50] observed that chilli plants treated with *Panchagavya* and vermicompost showed enhanced growth parameters, such as plant height (106 cm) and average number of branches (25), compared to the plants which were grown on vermicompost alone (85 cm and 15, respectively).

The highest values for plant height, number of leaves, fresh weight and dry weight of okra at seedling, flowering and yielding stages were observed when the plants were sprayed with 3% *Panchagavya* solution, compared to control (water spray) or other concentrations (1%, 5% and 7%) [51]. According to Boraiah et al. [52], spray of 6% *Panchagavya* recorded significantly higher fruit yield in capsicum, which might be due to the presence of growth regulators in *Panchagavya* and adequate supply of plant nutrients at different growth stages.

Foliar spray of 7.5% *Panchagavya* at 20, 40 and 60 DAS resulted in significantly higher growth in cowpea in terms of number of branches (7.63), number of leaves (24.16), leaf area (929.38 cm^2) and leaf area index (1.38) [53]. The auxin content in *Panchagavya* as well as the endogenous synthesis of native auxins upon its application might have led to cell division and elongation in the axillary buds, which had a promoting effect on the number of branches, leaves and leaf area. The plant growth parameters, viz. shoot length (cm), root length (cm), number of leaves and number of branches, of *Capsicum annuum* increased significantly over the control with application of *Panchagavya* [54]. Yadav et al. [55] revealed that, compared to other concentrations (i.e., 0% and 2%), growth attributes of tomato, viz. plant height, number of branches $plant^{-1}$ and plant spread, were significantly higher with 4% spray of *Panchagavya* at 30 and 60 DAT, and at harvest. The possible reason for higher values of all these growth parameters might be the presence of essential plant nutrients along with growth promoting enzymes in Panchagavya, which favoured rapid cell division and multiplication.

Panda et al. [56] recorded the highest values of growth parameters, viz. plant height (118.4 and 131.7 cm), stem girth (2.56 and 3.25 cm) and number of leaves $plant^{-1}$ (80.5 and 104.2) at 50 and 75 DAT, respectively, in tomato cv. Arka Rakshak, with foliar and soil application of 3% *Panchagavya*. Higher plant height obtained with application of *Panchagavya* may be attributed to presence of growth promotors, like auxins and gibberellins, and mineral nutrients present in it. Parmar et al. [57] revealed that tomato plants sprayed with 3% *Panchagavya* at 25 DAT recorded enhanced growth characters, such as plant height and number of primary branches $plant^{-1}$, under south Gujarat condition. Krishnan and Muthumperumal [58] recorded the maximum plant height (23.4 cm and 42.5 cm), number of leaves (143 and 218), number of lateral branches (8 and 9) and stem diameter (0.76 cm and 1.2 cm) at 35 DAS and 45 DAS, respectively, in tomato plants treated with 3% *Panchgavya*. Foliar spray of 5% *Panchagavya* resulted in maximum plant height (85.45 cm), leaf area (131.59 cm^2), leaf area index (3.66) and number of branches $plant^{-1}$ (21.3) in spiny brinjal [59]. *Panchagavya* contains auxins, like IAA, which are responsible for cell division and elongation, and hence, increased plant height. *Panchagavya* treatment produced maximum leaf area index which may be due to increased photosynthetic efficiency because of high nitrogen content.

Jakhar et al. [60] noticed significant increase in plant height (50.03 cm and 61.80 cm) and number of nodes (13.85 and 15.58) at 60 and 90 DAS, respectively, with foliar application of 6% *Panchagavya* on okra. The increase in plant height may be due to the fact that *Panchagavya* contains auxins, like IAA, which are responsible for cell division and elongation. Similarly, the increased number of nodes $plant^{-1}$ might be due to the application of *Panchagavya* at frequent intervals thus, supplying the required plant nutrients throughout the cropping season. Pradeepika et al. [61] recorded significantly greater plant height (121.71 cm), number of branches $plant^{-1}$ (5.47), number of nodules $plant^{-1}$ (15.00) and plant dry weight (20.31 g) in cowpea with 3% *Panchagavya* sprayed at 7 days interval. The maximum plant height (1.59 m) and number of branches (36.66) were observed in cherry tomato by James et al. [62] on treatment of *Panchagavya* @ 120 ml L^{-1} of water through fertigation. Netwal et al. [63] concluded that foliar application of 5% *Panchagavya* at 30 DAT registered significantly higher plant height (71.95 cm), number of leaves $plant^{-1}$ (31.12), leaf area (3068 cm^2), total chlorophyll a content in leaves (3.09 mg g^{-1}) and days to curd initiation (63.61) in sprouting broccoli. Application of *Panchagavya* might have contributed to increase in the beneficial microbial population in soil, which improved enhanced plant growth by improving the availability of nutrients and growth hormones to the plants. Rana [64] reported that among different concentrations, 5% foliar spray of *Panchagavya* produced the longest vine (140.50 cm) in bitter gourd.

4.2 Effect on yield parameters

Swain et al. [65] revealed that foliar application of *Panchagavya* at 3% concentration at 10 days interval produced the highest fruit set (56.25%), fruit length (5.00 cm), yield plant^{-1} (86.95 g) and yield ha^{-1} (21.95 q) in chilli cv. Kuchinda local. The florigen hormone and auxins present in *Panchagavya* helped in production of a greater number of flowers and minimising flower drop, respectively, which resulted in better fruit retention capacity. The higher yield may be due to the increase in photosynthetic activity of the plants as a result of the hormonal effect of *Panchagavya*, which further led to better source-sink relationship. Rao et al. [50] concluded that chilli plants treated with *Panchagavya* recorded higher values for average number of flowers (145), average number of green chillies per picking (20), number of pickings (10), total number of fruits (200), average fruit length (11 cm) and average fruit weight (0.95 g) compared to the untreated plants. They also observed considerable reduction in flower drop in the treated plants.

Foliar application of 6% *Panchagavya* significantly increased the yield (124.4 q ha^{-1}) over control (no spray) with 18.5% increase in green pod yield in French bean [66]. This was due to the presence of essential plant nutrients, vitamins, amino acids, growth-promoting substances and beneficial microorganisms in *Panchagavya*, which might have resulted in better source-sink relationship. Swarnam et al. [67] reported significantly greater number of fruits, single fruit weight and yield plant^{-1} in eggplant with foliar application of 3% *Panchagavya* compared to control (no spray). Taller plants with more branches increased the photosynthetic area, which might have resulted in more production and translocation of photosynthates, resulting in formation of more fruits with larger size, ultimately leading to higher fruit yield. The highest number of fruits (19) and individual fruit weight (30.67 mg) in okra were recorded with foliar spray of 3% *Panchagavya* solution, compared to control (water spray) as well as other concentrations (1%, 5% and 7%) [51]. The balanced availability of vitamins, minerals and amino acids coupled with the action of beneficial microorganisms (e.g., *Lactobacillus*) from the different components of *Panchagavya* resulted in increased crop yield.

Gajjela and Chatterjee [68] recorded increase in fruit length (39.78%), number of fruits plant^{-1} (9.35%), single fruit weight (23.19%), fruit yield plant^{-1} (35.64%), fruit yield plot^{-1} (35.09%) and fruit yield ha^{-1} (34.98%) in bitter gourd with sprays of 3% *Panchagavya* at 20, 40 and 60 DAS, which may be due to translocation of more amount of carbohydrates to developing fruits. Also, *Panchagavya* contains coconut water, which contains kinetin, which increases biomass and yield. On application of 7.5% *Panchagavya* in cowpea, Sutar et al. [53] recorded significantly higher grain yield and haulm yield with an increase of 17.17% and 12.31%, respectively, compared to no application of *Panchagavya*. Similarly, maximum 100-seed weight (11.71 g) and seed weight per plant (8.06 g) were noticed with foliar spray of 7.5% *Panchagavya* applied at 20, 40 and 60 DAS compared to no foliar spray of *Panchagavya*.

In tomato, Yadav et al. [55] observed significantly higher number of flowers plant^{-1}, number of fruits plant^{-1}, fruit size and average fruit weight with spray of 4% *Panchagavya*. The significant enhancement in yield attributes and yield may be attributed to the combined effect of increased supply of plant nutrient ions and biofertilisers present in *Panchagavya*, and increased allocation of food materials to the developing fruits. Panda et al. [56] recorded the maximum yield attributes, viz. fruit length (5.60 cm), number of fruits plant^{-1} (46.1), fruit diameter (4.41 cm) and fruit yield plant^{-1} (2.81 kg) in tomato cv. Arka Rakshak with foliar and soil application of 3% *Panchagavya*, which may be attributed to the presence of growth promoters like auxins and gibberellins in *Panchagavya*.

Nanthakumar et al. [59] recorded maximum values for number of flowers plant^{-1} (55.5), number of fruits plant^{-1} (20.9), fruit length (5.8 cm), fruit circumference (14.7 cm), individual fruit weight (82.1 g) and fruit yield (37.8 t ha^{-1}) in spiny brinjal on foliar application of 5% *Panchagavya*. The translocation of cytokinins to axillary buds converted most of them into reproductive growth, resulting in higher number of fruits. Increased fruit weight might be due to improved photosynthesis and better provision of plant nutrients. The cumulative effect of better fruit set, lesser fruit drop and development of individual fruits resulted in enhanced fruit yield. Thus, the availability of growth hormones and plant nutrients, and then effective diversion towards the sink could be the reasons for increased yield and yield-attributing parameters. In okra, with the foliar application of 6% *Panchagavya*, Jakhar et al. [60] recorded significant increase in the number of flowers plant^{-1} (17.38 and 24.91) at 60 and 90 DAS, respectively, and number of fruits plant^{-1} (18.86) as compared to control (no spray). Pradeepika et al. [61] observed significantly higher number of pods plant^{-1} (7.27), number of seeds pod^{-1} (12.33), seed yield (1.28 t ha^{-1}) and stover yield (4.02 t ha^{-1}) in cowpea with application of 3% at 7 days interval. The highest harvest index (23.24) was also noted under the same treatment.

James et al. [62] recorded the minimum number of days to first flowering (43.6) and 50% flowering (58.0), and maximum number of flowers cluster^{-1} (10.23), number of fruit set cluster^{-1} (8.8), number of fruits plant^{-1} (152.80), fruit weight (5.6 g), fruit diameter (5.5 cm) and fruit yield ha^{-1} (58.81 t) in cherry tomato plants treated with *Panchagavya* @ 120 ml L^{-1} of water. Foliar spray of 5% *Panchagavya* at 30 DAT significantly enhanced the curd yield (29.41 t ha^{-1}) in sprouting broccoli in semi-arid climatic conditions [63]. The presence of essential plant nutrients, like N, P, K, Fe, Mn and Zn, and several plant growth-promoting hormones, such as auxins, cytokinins and gibberellins, is responsible for various growth and developmental processes in plants, including cell division, elongation and differentiation, leading to increased yield. Also, the availability of plant nutrients for longer period of time due to the activities of beneficial soil microbes, like *Azospirillum*, *Azotobacter*, Phosphobacteria and *Pseudomonas*, as well as *Lactobacillus* from *Panchagavya*, reflected in better yield attributes and overall yield of broccoli.

Purohit et al. [69] revealed that foliar spray of 6% *Panchagavya* at 20 and 40 DAS in addition to 80% RDF proved superior with respect to number of clusters $plant^{-1}$ (14.93), number of pods $cluster^{-1}$ (8.56), average pod weight (1.67 g), green pod length (12.85 cm), pod yield $plant^{-1}$ (152.12 g), pod yield $plot^{-1}$ (1.77 kg) and pod yield ha^{-1} (109.46 q) in cluster bean. This might be due to the combination of increased nutrient uptake, production of growth regulators in the cells, improved photosynthesis and increased diversion of food material to the sink (pods). Among different concentrations of *Panchagavya*, Rana [64] observed better results with respect to days to first harvest (49.778), number of fruits $plant^{-1}$ (41.556), fruit length (14.344 cm), fruit girth (17.678 cm), average fruit weight (153.667 g), average fruit yield $plant^{-1}$ (56.760 kg), average fruit yield $plot^{-1}$ (5.66 kg) and total yield (56.76 t ha^{-1}). The highest pod yield $plot^{-1}$ (4.08 kg) and pod yield ha^{-1} (118.76 q) in pea were obtained with application of 4% *Panchagavya*, which were, respectively, 43.15% and 43.08% higher than control [70]. This might be attributed to increased chlorophyll synthesis and cell division in the leaves due to availability of essential plant nutrients and growth-promoting substances in *Panchagavya*, and their faster absorption through leaf cuticles.

4.3 Effect on biochemical and quality parameters

Panchagavya contains almost all the essential nutrients and growth hormones, which enhance the enzymatic activity of seeds and support better germination and vigour [32,71,72], and improves nutrient uptake and utilisation in plants. Better availability and uptake of plant nutrients helps in synthesis of chlorophyll and other pigments (e.g., lycopene and carotenoids), and increases total soluble solids (TSS), ascorbic acid content etc. Application of *Panchagavya* increases allocation of nitrogen for production of secondary metabolites, such as phenols, which serve as natural defense systems in plants [67]. A review on the effect of application of *Panchagavya* on biochemical and yield parameters of vegetable crops has been produced in Table 3.

Table 3: Effect of *Panchagavya* on biochemical and quality parameters of vegetable crops

Crop	Concentration, method and time of application	Effect	Reference
Tomato	3% as foliar and soil application	Maximum chlorophyll a, chlorophyll b, total chlorophyll, carotenoids, TSS, ascorbic acid and lycopene content	Panda et al. [56]
	10% as seed priming treatment for 12 hours	Maximum germination percentage, root and shoot length, seedling length, fresh weight and dry weight, and seed vigour index	Marmat Sandip et al. [73]
Cherry tomato	120 ml L^{-1} of water through fertigation	Increase in total soluble solids and ascorbic acid content	James et al. [62]
Eggplant	3% as foliar application at 15 days interval	Increased total phenolic content, total carotenoids, DPPH activity and ascorbic acid	Swarnam et al. [67]
Chilli	3% as foliar application at 10 days interval (6 sprays)	Increase in chlorophyll and ascorbic acid content	Swain et al. [65]
	3% as foliar spray along with 5% *Verticillium luccani* at 30 and 60 DAT	Highest ascorbic acid and chlorophyll content	Ranjitha et al. [74]
Okra	3% as foliar spray at	Highest chlorophyll a, chlorophyll b	Rakesh et al. [51]

	weekly interval up to 45 DAS	and carotenoid content	
	3% as foliar spray at 30, 45, 60 and 90 DAS	Maximum ascorbic acid, fiber and iodine content in fruits	Verma et al. [75]
	6% as foliar application	20.23% higher crude protein content over control	Jakhar et al. [60]
Bitter gourd	3% as foliar spray at 20, 40 and 60 DAS	Increase in total soluble solids, ascorbic acid and protein content	Gajjela and Chatterjee [68]
	5% as foliar spray at 15, 30 and 40 days after emergence of two true leaves	Maximum TSS and vitamin C in fruits	Rana [64]
Ridge gourd	3% as seed priming treatment for 12 hours	Highest germination percentage, root and shoot length, seedling length, fresh weight and dry weight, and seed vigour index	Kumari et al. [76]
Sprouting broccoli	5% as foliar spray at 30 DAT	Significant improvement in total chlorophyll a content in leaves	Netwal et al. [63]
Carrot	5% as seed priming treatment	Highest field emergence, seed germination percentage, speed of germination, seedling vigour index, dehydrogenase enzyme activity, α-amylase activity and lowest electrical conductivity	Sowmeya et al. [77]

4.4 Effect on soil properties

According to Ali et al. [78], soil parameters exhibited significant improvement after one year of organic cultivation of *Capsicum frutescens* using 3% *Panchagavya* solution. They reported that the pH and EC became closer to neutral (pH from 6.8 to 7.0 and EC from 0.2 to 0.3 mmhos), organic carbon increased from 0.71% to 1.5%, and availability of phosphate and potash increased to an extent of more than three times and two times, respectively. Jain et al. [79] recorded the maximum values for organic carbon, macronutrients, viz. nitrogen, phosphorus and potassium, and micronutrients, viz. zinc, copper and manganese, compared to vermicompost and FYM. They also stated that *Panchagavya*-applied soil contained multifold higher microbial (bacterial and fungal) population and basal respiration compared to vermicompost and FYM. This might be due to the fact that *Panchagavya* contained all these nutrients in higher quantities than vermicompost and FYM. The soils enriched with *Panchagavya* showed significantly higher basal respiration due to higher microbial population, which was a result of higher availability of organic matter and nutrients.

Kumbar and Devakumar [66] recorded significantly higher population of bacteria, fungi, actinomycetes, P-solubilisers and N-fixers (40.67×10^6, 25.58×10^4, 29.92×10^3, 29.75×10^5 and 29.83×10^5 cfu g^{-1}, respectively) in soil on application of 6% *Panchagavya* in French bean at 40 DAS. *Panchagavya* contains enormous amount of microbial load which multiplies in the soil and acts as a tonic to enhance the microbial activity in soil. Boraiah et al. [45] also reported that *Panchagavya* spray had significant effect on the population of nitrogen fixers and P-solubilisers in post-harvest soils of capsicum crop. Spraying of 6% *Panchgavya* recorded higher number of N-fixers (23.68×10^3 and 25.59×10^3 cfu g^{-1} at 60 DAT, and 17.77×10^3 and 17.18×10^3 cfu g^{-1} at harvest during *kharif* and summer, respectively) as well as P-solubilisers (28.43×10^3 and 33.04×10^3 cfu g^{-1} at 60 DAT, and 27.46×10^3 and 34.53×10^3 cfu g^{-1} at harvest during *kharif* and summer, respectively) compared to control. *Panchagavya* contains macronutrients like N, P and K, micronutrients, vitamins, essential amino acids, and growth promoting factors like IAA and GA, which provide nutrition to the rhizospheric microbes, thereby increasing their population in soil.

In field bean (*Dolichos lablab*), Devakumar et al. [80] observed that, among different levels of *Panchagavya* (0%, 2.5% and 7.5%), significantly higher populations of bacteria, fungi, actinomycetes, N-fixers, *Pseudomonas* and phosphate solubilising bacteria (PSB) were recorded in the rhizospheric soil, obtained just before harvest, with foliar spray of 7.5% *Panchagavya*. Application of *Panchagavya* at vegetative, flowering and pod development stages of crop growth provided more nutrients for the soil-dwelling microorganisms to multiply, thereby increasing their population. Gajjela and Chatterjee [81] studied the effect of liquid organic manures on post-harvest available soil nutrients in bitter gourd and reported that, among the different number of sprays of *Panchagavya*, the highest available soil organic carbon (0.99%) was recorded in the treatment that received 3% *Panchagavya* at 20, 40 and 60 DAS. The microbes present in *Panchagavya* decomposed the organic matter added by the basal organic manures, which resulted in increased organic carbon content of the soil.

Diwaker et al. [82] reported increased microbial population post-harvest soils of cauliflower crop, where higher population of bacteria, fungi and actinomycetes (64.2×10^6, 26.8×10^4 and 34.9×10^4 cfu g^{-1}, respectively) was observed in case of 3% *Panchagavya* spray, compared to other liquid formulations. Yadav et al. [70] recorded the maximum available nitrogen (341.0 kg ha^{-1}) in post-harvest soil of pea under application of 4% *Panchagavya*. This might be due to the fact that the liquid formulation of *Panchagavya* contains essential plant nutrients, growth hormones and beneficial microorganisms such as *Azospirillum*, *Azotobacter*, Phosphobacteria and *Pseudomonas*, which might have played an important role in root development and proliferation, resulting in better nodule formation and nitrogen fixation.

4.5 Effect on diseases and insect-pests

Application of *Panchagavya* as seed treatment led to a significant decrease in *Phytophthora* blight and anthracnose in capsicum [83], and early blight in tomato [84]. Rathore and Patil [85] observed inhibition up to 66.7% and 83.3% in *Fusarium solani*, and 100% and 100% inhibition in *Sclerotium rolfsii* at 5% and 10% *Panchagavya*-amended potato dextrose agar (PDA), respectively, thereby making *Panchagavya* suitable for integrated disease management programme against damping-off disease of vegetable crops. Jahagirdar et al. [86] explored the efficacy of modified *Panchagavya* mixture (MPG-3) in managing various plant diseases, including *Fusarium* wilt in tomato, foot rot in black pepper and damping off in tomato in nursery and main field, and concluded that MPG-3 was effective in reducing *Fusarium* populations in the treated crops. Additionally, the study demonstrated the potential of MPG-3 in eco-friendly and cost-effective disease management, highlighting its role in integrated disease management strategies.

Pazhanisamy and Archunan [87] investigated the effectiveness of *Panchagavya* combined with various plant extracts against the shoot and fruit borer (*Earias vittella*) on okra and suggested NSKE (neem seed kernel extract) in combination with *Panchagavya* as an effective and eco-friendly alternative for managing *E. vittella* infestations, potentially replacing synthetic pesticides. Rajput et al. [88] assessed the effectiveness of *Panchagavya* and botanical pesticides against the diamondback moth (*Plutella xylostella*), a major cabbage pest. Results showed that treatments like *Panchagavya* 10% + NSKE 5% and *Panchagavya* 5% + NSKE 5%, along with Spinosad 45 SC, proved most effective in reducing larval populations, outperforming other treatments significantly.

4.6 Effect on economics

The net returns and benefit-cost ratio (B:C or BCR) have a stronger impact on the practical utility and adoption of any technology, and should not be overlooked in case of application of *Panchagavya* in vegetable crops.

Gopakkali and Sharanappa [89] recorded the highest net returns (Rs. 3,61,557 ha^{-1}) and benefit-cost ratio (4.27) with the application of EBDLM (Enriched bio-digested liquid manure) at 100 kg N eq. ha^{-1} + Three sprays of 3% *Panchagavya* in onion, compared to other concentrations of *Panchagavya*. Similarly, Bhawariya et al. [90] observed the highest net returns (Rs. 29,563 ha^{-1}) and B:C (2.38) with the application of 3% *Panchagavya* in cluster bean. In okra, Hathi et al. [91] recorded the maximum net returns (Rs. 1,62,170 ha^{-1}) and BCR (2.62) with foliar application of 3% *Panchagavya* at 20, 40, 60 and 80 DAS along with 100% RDF. The highest net returns (Rs. 98,971.90 ha^{-1}) and benefit-cost ratio (2.54) were obtained in the treatment combination of nitrogen @ 20 kg ha^{-1} + 5% *Panchagavya* in cowpea Raja and Singh [92]. In Fenugreek (*Trigonella foenum-graecum*), Saini et al. [93] observed that spray of 4% *Panchagavya* at pre-flowering and pod setting recorded the highest net return (Rs. 34,259 ha^{-1}) and B:C (2.14). Among various organic sources used as foliar application, Sakpal et al. [94] recorded the highest net returns (Rs. 21,239 ha^{-1}) and BCR (1.29) in cowpea when sprayed with 3% *Panchagavya*. The highest net returns (Rs. 4,97,539 ha^{-1}) and benefit-cost ratio (5.49) were obtained with spray of *Panchagavya* @ 120 ml L^{-1} of water on cherry tomato [62]. Purohit et al. [69] recorded the highest net returns (Rs. 2,09,853 ha^{-1}) and B:C (2.77) in cluster bean with the application of 80% RDF + Foliar spray of 6% *Panchagavya* at 20 and 40 DAS. The foliar spray of 5% *Panchagavya* recorded the highest net returns (Rs. 2,30,256 ha^{-1}) and BCR (3.60) in sprouting broccoli [63].

The increased economic parameters obtained with application of *Panchagavya*, either alone or in combination with other nutrient sources, can be attributed to the significant improvement in yield under the same treatment(s). Also, the cost of cultivation due to the use of *Panchagavya* were lower, as this organic formulation is cost-effective compared to the chemical or synthetic fertilisers [95,96].

5. CHALLENGES AND LIMITATIONS

Panchagavya, an organic liquid manure, while offering numerous benefits, also comes with its share of challenges and limitations that need to be addressed for its successful implementation in vegetable cultivation. Some of these challenges and limitations include:

5.1 Limited availability and site-specific nature of raw materials

The availability of raw materials for *Panchagavya* is directly linked to the population of cows. In regions with low density of cows, or where rearing of cows is not common, such as industrial or urban areas, obtaining the required quantities of cow dung, urine, milk, curd and ghee can be quite challenging. Also, the availability of raw materials can vary seasonally. For example, during the rainy season, when cows spend more time indoors, collecting fresh cow dung and urine may be more difficult. Similarly, variations in milk production throughout the year can affect the availability of milk and milk-derived products like curd and ghee.

5.2 Knowledge and awareness gap

The knowledge and awareness gap among farmers, researchers and extension workers, about *Panchagavya*, may impede its widespread adoption and optimization. In regions where traditional vegetable farming practices are prevalent, farmers may have practical knowledge and experience in using *Panchagavya* based on oral and local wisdom; however, they may lack scientific understanding or access to technical information about its optimal use.

5.3 Slow response

The term "slow response" in the context of *Panchagavya* refers to the delayed or gradual effects observed in plant growth and yield, soil fertility, or pest and disease control after application. This delayed response contrasts with chemical fertilisers and pesticides, which often yield more rapid and observable effects.

5.4 Complexity of microbial composition

The efficacy of *Panchagavya* is largely influenced by the intricate interactions within its microbial community. The microbial composition of *Panchagavya* can vary depending upon the source of raw materials, conditions prevailing during fermentation and handling practices. Inconsistent microbial composition may lead to variability in the efficacy of *Panchagavya* and make it challenging to standardise its production and application.

5.5 Dependency on environmental conditions

The fermentation process in preparation of *Panchagavya* is mediated by various microorganisms, the activity and composition of which can vary significantly depending on environmental factors such as temperature and humidity. Extremes of temperature or large fluctuations can inhibit microbial growth or lead to the proliferation of undesirable microorganisms, altering the final quality of *Panchagavya*. Seasonal changes also affect the availability and quality of raw materials used in preparation of *Panchagavya*. For example, the composition of cow dung and urine, and nutritional quality of milk, are influenced by factors such as diet, hydration and health status of the cows, which may fluctuate seasonally.

Different geographical regions may harbour distinct microbial populations with varying metabolic capabilities, which can affect the fermentation process and the resulting characteristics of *Panchagavya*. Additionally, variations in soil composition and fertility levels can affect the availability and uptake of nutrients released by *Panchagavya* in the fields.

5.6 Limited control

Unlike synthetic fertilisers where nutrient composition can be precisely controlled, the composition of *Panchagavya* can be more challenging to predict and control.

5.7 Risk of potential contamination

The use of cow dung and urine in preparation of *Panchagavya* raises concerns about potential contamination with pathogens, heavy metals, antibiotics and other harmful substances. The use of diseased cows can increase the risk of microbial contamination and transmission of diseases to plants, animals and humans. Likewise, the presence of antibiotic residues in cow urine and dung from veterinary treatments can pose health risks to consumers if residues persist in the edible parts of vegetables.

5.8 Limited nutrient availability

Panchagavya might not provide nutrients in the same concentrated form and rapid manner as chemical fertilisers. This could pose limitations in situations when a quick nutrient supply in high doses is required.

5.9 Limited shelf life and stability

Panchagavya is a “biological product” containing various nutrients, enzymes, hormones and microorganisms that undergo chemical and microbial degradation over time. Factors such as temperature, humidity, exposure to sunlight and microbial activity can affect the stability and shelf life of this organic formulation. Without proper storage conditions and preservation techniques, the efficacy of *Panchagavya* may decline rapidly, leading to reduced benefits and economic losses for farmers.

6. FUTURE PROSPECTS AND RESEARCH NEEDS

The future prospects of *Panchagavya* as a biofertiliser, bioenhancer and biopesticide are promising keeping in view the increasing importance of sustainable vegetable cultivation globally. However, to ensure its success and refinement, several key research needs must be addressed:

6.1 Scaling up for large-scale adoption

While the traditional roots and potential benefits of *Panchagavya* make it an attractive option for sustainable agriculture, intensive research is needed to ensure its integration into mainstream vegetable farming as well as its feasibility and impact on broader scale.

6.2 Knowledge dissemination

Bridging the knowledge gap between researchers and farmers is important. Developing effective methods of disseminating research findings and educating farmers about the benefits of *Panchagavya* should be made a priority.

6.3 Crop-specific approaches

Research should focus on developing standardised crop-specific dosages of *Panchagavya* that correspond to different growth stages and nutritional requirements.

6.4 Climate resilience

Research related to stress tolerance, microbial diversity, carbon sequestration, water conservation and biodiversity promotion, in addition to soil health improvement and enhanced plant growth and development, is crucial as it can provide insights into mitigating the challenges faced in vegetable cultivation due to global climate change.

6.5 Innovative formulations

Research into novel formulations, such as combining *Panchagavya* with other manures, such as *Jeevamrit*, vermiwash, vermicompost, biochar etc., can lead to more effective and versatile nutrient solutions.

6.6 Economic viability

Evaluating the economic feasibility of preparation and application of *Panchagavya* compared to conventional methods is essential to ensure long-term economic benefits, cost-effectiveness and higher returns on investment.

6.7 Policy support

Research should provide evidence-based recommendations to promote sustainable vegetable cultivation practices and advocate for policies that incentivise and support adoption of *Panchagavya* in vegetable fields.

7. CONCLUSION

The application of *Panchagavya* in vegetable crop production holds promise as a sustainable and effective approach. Through its diverse composition of cow-derived products, *Panchagavya* offers a unique blend of nutrients, growth regulators and beneficial microorganisms that can enhance soil fertility, plant growth and resistance/tolerance to insect-pests and diseases. The extensive research reviewed herein demonstrates the positive effects of *Panchagavya* on various aspects of vegetable crop production, including increased growth and yields, improved quality traits, enhanced biotic stress tolerance and higher returns per investment. Moreover, the organic nature of *Panchagavya* aligns with the principles of sustainable agriculture by reducing reliance on synthetic inputs and minimising environmental impacts. It promotes soil health and biodiversity, and contributes to long-term agricultural sustainability. In addition to that, the accessibility and affordability of *Panchagavya* make it a viable option for smallholder farmers, particularly in the resource-constrained areas. However, further research is needed to optimize *Panchagavya* formulations and application methods for different vegetable crops and agroecological conditions, which is possible with long-term field trials and comparative studies with conventional practices. Overall, this review underscores the potential of *Panchagavya* as a valuable tool for sustainable vegetable production, offering a holistic approach that combines indigenous traditional knowledge with modern agricultural practices. Embracing *Panchagavya* can contribute to food security, environmental conservation and seek the world's attention towards India's rich traditional practice and literature.

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