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Review

Effects of Organic Farming on the Physicochemical, Functional, and Quality Properties of Pomegranate Fruit: A Review

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Abstract: In this review, a selection of studies was carried out that evaluated the influence of organic agronomic practices on the cultivation of pomegranate; specifically, the influence of these practices on improving soil health and pomegranate fruit quality. Studies were selected (n = 39) in which organic treatments were applied to different cultivars of pomegranate and which evaluated fruit and soil quality parameters. These studies showed that exclusively organic manure and organic manure in combination with mineral fertilizers are suitable to fulfill the requirements of pomegranate crop and reduce the amount of mineral fertilizers. Moreover, the soil health improved with organic manures, as well as growth, and yield in the pomegranate crop. Pomegranate fruits grown under organic conditions showed high levels of fruit quality parameters, such as total soluble solids and fruit juice, and additionally presented high concentrations of bioactive compounds such as anthocyanins and total phenols. Data from these studies endorsed the fact that pomegranates cultured under organic conditions may have a better fruit quality and nutraceutical content than those grown under conventional conditions, although more scientific evidence is required to confirm this.

Keywords: pomegranate; organic; quality; eco-friendly; bioactive compounds; soil

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1. Introduction

Pomegranate (*Punica granatum* L.) is one of only two species in its genus, Punica, which is the sole genus in the family Punicaceae. This crop is considered native to the region extending from Iran to northern India and has spread throughout the Mediterranean area [1]. The fruit has a berry-like appearance, with a leathery husk enclosing many seeds surrounded by juicy arils that form the edible part of the fruit. Depending on the cultivar, the arils can range in color from deep red to almost colorless, while the enclosed seeds vary in the amount of sclerenchyma tissue present, which affects their softness [1]. The fruit also features a prominent calyx that remains intact until maturity, serving as a distinct identifying characteristic. Over 500 pomegranate cultivars have been named, each with unique traits such as fruit size, husk color (ranging from yellow to purple, with pink and red most common), aril color (ranging from white to red), seed hardness, maturity, juice content, acidity, sweetness, and astringency [2]. There is interest in identifying or developing cultivars that have more locules to fill the fruit interior, fewer septal membranes for easier eating, and a thinner mesocarp [1].

Pomegranate is getting increasing attention for its health-promoting effects. The fruit is a rich source of phenolics (primarily ellagic acid and punicalagin), hydrolysable tannins, anthocyanins, flavonoids, and essential micronutrients such as vitamin C [3]. The chemical preparations of pomegranate fruit showed strong antioxidative, anti-inflammatory, apoptotic, and antimutagenic properties, with the antioxidant content of pomegranate juice being among the highest of any foods. Regular consumption of this fruit has been associated with the prevention of gastric damage, cardiovascular disease, type 2 diabetes mellitus, specific types of cancers, renal illnesses, liver complications, and osteoarthritis [3–6].

The three main pomegranate-producing countries are India, China, and Iran, bringing together just over 80% of world production, which is around 4.9 million tons and an estimated cultivated area of approximately 455,200 ha [7]. In Spain, there are 5716 ha of pomegranate cultivation, which represents a production of 75,763 t [8]. Spain is the largest European exporter of pomegranates, with the main destination markets being European Union countries. The Valencian Community accounts for 70% of the area and more than 78% of the Spanish pomegranate production [8,9]. In India, the main producing country, pomegranate is cultivated in vast areas of marginal lands having very low organic carbon content and microbial population where yields are limited due to deficiency of more than 2–3 nutrients [10,11]. Under these circumstances, attempts are being made to improve production by adopting high external input agriculture practices during the last few decades. Over the course of time, indiscriminate use of fertilizers, pesticides and other chemicals has resulted in irrecoverable deterioration of soil physical, chemical, and microbiological health, and the extensive use of chemical fertilizers affecting soil health results in decreased soil productivity [11,12]. In view of this, concepts including organic pomegranate cultivation, as claimed to be the benign alternative for sustainable production, would play a vital role [11]. The use of biofertilizers is being sought to maintain and improve soil quality and productivity levels at low input costs [13]. Organic sources help to conserve soil health, maintain organic matter, and soil microflora equilibrium, ultimately helping to improve physical, chemical, and biological soil properties [14,15].

Due to the increasing of health consciousness, the demand for organically produced pomegranate fruits is rising in the Middle East, America, and European countries. To achieve this, a more rational approach to organic cultivation is needed, including the use of locally available organic materials such as farmyard manure, vermicompost, poultry manure, and green manuring. This practical implementation of organic methods can restore soil fertility and enrich the pool of nutrients available to pomegranate plants, which can enhance crop quality, increase plant tolerance to pests and diseases, and result in longer maturity time [11,16,17]. Therefore, there is a great need to generate comprehensive information about organic manures applied to pomegranate crop and their impact on improving soil and fruit quality, which are the objectives of this review.

2. Scientific Literature Review

To conduct this review, the authors utilized a research paper format and a scoping review methodology. The review followed the PRISMA Extension (PRISMA-ScR) approach [18], which included a comprehensive literature search of the Scopus and ScienceDirect databases in September 2022. The search was limited to articles published in English since 1990 and focused on several key concepts (*Punica granatum*, pomegranate, organic, quality, bioactive compounds, eco-friendly, and treatments). The authors prioritized studies published in journals included in the Journal Citation Reports and selected only research papers that included experimental design and data treatment. Figure 1 provides a visual representation of the search process. The structure of the review allows a dissection of: (i) organic treatments applied in pomegranate crop, (ii) influence of these treatments in yield and growth, and (iii) influence of these treatments in fruit quality parameters.

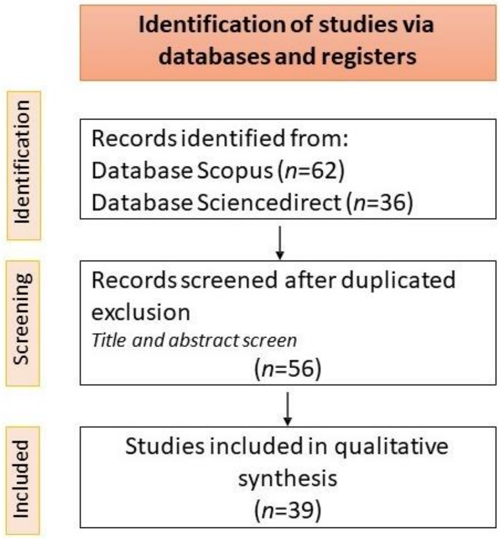

Figure 1. Flow diagram describing the study selection process of scientific literature.

3. Organic Treatments Applied in Pomegranate Crop and Their Effect on Soil and Yield

Table 1 shows different organic treatments applied to pomegranate crop and quality and yield data of each pomegranate cultivar under these treatments. Many management practices, fertilizer application, and manuring are carried out to improve the soil physical environment [19]. Farmyard manure (FYM) is a decomposed mixture of urine, dung, litter, and leftover materials from fodder fed to animals and roughages. FYM with a great level of decomposition contains 0.5–1.5% N, 0.2–0.4 P_2O_5, and 0.5–1.0% K_2O. Moreover, FYM is a good source of organic carbon, which activates the biotic life of soil flora and fauna [20]. Marathe et al. [10] applied farmyard manure at the rate of 20 kg tree^{-1} and thoroughly mixed with soil material before plantation of pomegranate trees cv. 'Bhagwa' seedlings. These authors found that organic carbon content was significantly higher in the organic manuring treatments that they applied (0.56–1.18%) than inorganic fertilizer (0.46%) and the control (0.42%), with FYM being the treatment which showed the highest organic carbon in the soil (1.18%) [11]. Increased organic carbon content with the incorporation of FYM was corroborated by studies in guava [21]. It may be noted that the buildup of organic carbon was not in proportion to the quantity of organic manure applied. This might have been due to variation in the amount applied, nutrient composition, decomposition, and release pattern of different organics in the soil [11]. Mir et al. [14] applied 20 kg tree^{-1} of FYM in combination with other organic manuring treatments in pomegranate crop cv. 'Kandhari Kabuli': NPK, vermicompost, and green manuring biofertilizer in different proportions. The treatment of 20 kg tree^{-1} of vermicompost, 80 g tree^{-1} of biofertilizer, 20 kg tree^{-1} of FYM, green manure in situ and the recommended doses of fertilizer (NPK100 + 20 kg tree^{-1} of vermicompost) resulted in the maximum annual shoot extension growth (57.03 cm), followed by the same treatment but with the 100% (46.93 cm) and the 75% (44.71 cm) and 50% (38.16 cm) of the recommended dose of NPK. This increase in growth is attributed to the increased uptake of nutrients and increased release of growth factors such as auxins, gibberellins, and cytokinin in the root zone by microbial inoculants in rhizosphere soils [14].

Vermicompost is a process of organic waste decomposition that involves the addition of earthworms, such as *Eisenia fetida*, *Eudrilus eugeniae*, or *Perionyx excavates*, to aid in the waste stabilization process. This process relies on a symbiotic interaction between the earthworms and microorganisms to produce a stable, homogeneous, and humus-like final product known as vermicompost [22,23]. Recent studies have shown that using organic fertilizers such as vermicompost enhances levels of soil organic matter, soil microbial biomass, and activities [23,24]. Furthermore, vermicompost has been linked to an increase in plant growth, which may be attributed to biological effects, such as increases in beneficial enzymatic activities and populations of beneficial microorganisms, as well as the presence of biologically active plant growth-influencing substances such as plant growth regulators or hormones and humic acids in the vermicompost [23,25]. Marathe et al. [11] found that application of vermicompost (20 kg tree^{-1}) and green manuring with sun hemp increased macro-nutrient uptake by pomegranate plants and obtained the highest plant height (140 cm) and plant spread (127.9 cm) with the application of vermicompost in pomegranate trees. The humic acids that vermicompost presents contain sulfur, nitrogen, and phosphorus in varying amounts, and metals such as Ca, Mg, Cu, and Zn. Humic acids act by stimulating plant growth, vegetal enzymes, nutrient uptake, and beneficial soil microorganisms, and may also increase root growth similarly to auxin [26,27]. Abad-Ella et al. [26] applied different doses of humic acid (12.5 and 25 g tree^{-1} of hummer 86% potassium humate as soil application) in the first week of February for two consecutive years, and determined that these treatments increased vegetative growth, fruit set and yield in pomegranate crop cv. 'Arabi'. According to this study, the combination of humic acid and the recommended rate of mineral nutrients (NPK) at a rate of 25 kg tree^{-1} was found to be the most effective treatment in promoting shoot length, number of leaves per shoot, and leaf area of 'Arabi' pomegranate trees [26]. The data indicated that the application of humic acid with both concentrations, either alone or in combination with 50% of the recommended rate of mineral fertilizer, significantly increased growth parameters in pomegranate crops, including fruit set and fruit yield (measured by the number or weight of fruit tree^{-1}). This was attributed to the ability of humic acid to increase the availability of most nutrients and improve the physical and chemical properties of soil [26]. The most effective treatment to increase yield in terms of the number and weight of fruits tree^{-1} was found to be 50% of the recommended rate of NPK combined with 25 g of humic acid tree^{-1}. In pomegranate crops of 'Altaayifaa', 'Manfaluty' and 'Wonderful' cultivars, Hammad and El-Sagheer [28] applied 14 kg tree^{-1} of a native commercial product of vermicompost. Results indicated that this treatment increased plant fresh weight (29.1%) and shoot dry weight (93.4%), and additionally had a significant effect on the reduction of the root-knot nematode *Meloidogyne incognita*, one of the most important and harmful plant-parasitic nematodes in most pomegranate cultivation regions.

Vermicompost (VC) can be enriched with other eco-friendly products, including species of *Trichoderma*, which are commonly utilized as commercial formulations of biological control and plant growth promoters [29]. The common saprophytic fungi, *Trichoderma asperellum* (as a microbial inoculant), is an effective eco-friendly alternative method of controlling plant pathogens [30,31]. Hammad and El-Sagheer [28] used vermicompost with a commercial bio-product composition of *T. asperellum* containing 10% nitrogen, 10% phosphorus and 10% potassium at a rate of 3.3 mL tree^{-1} to compare eco-friendly strategies in the control of root knot nematode, *M. incognita*, infecting pomegranate orchards under greenhouse and open field conditions. Results indicated that this treatment had a significant effect on the reduction of *M. incognita*, decreasing their population by 69.6% after their application, increasing plant fresh weight by 17.7% and shoot dry weight by 44.3%. These authors also determined that the application of 1.2 g tree^{-1} of a commercial bio-product of chitosan, an eco-friendly product extracted from the shell of crabs, increased plant fresh weight by 56.25% and shoot dry weight by 105.8%, in addition to showing a significant effect in the reduction of *M. incognita*.

Poultry manure (PM) is the organic waste material from poultry consisting of animal feces and urine. Poultry manure is a rich organic manure since solid and liquid excreta are excreted together resulting in no urine loss. In fresh poultry excreta, uric acid or urate is the most abundant nitrogen compound (40–70% of total N) while urea and ammonium are present in small amounts [32]. Marathe et al. [11] found that that the highest P (0.182%), K (1.06%), and Fe (176.7 ppm) contents in pomegranate tree leaves were supplied by PM, increasing soil N content. Pomegranate crop cv. 'Bhagwa' showed the maximum yield with the treatments that these authors applied.

Green manures (GM) are quick-growing crops specifically for the purpose of improving soil physical structure and fertility, though they may also have other functions. They are normally incorporated back into the soil, either directly (in situ) or after removal and composting (ex situ). In situ green manuring, especially with legumes, had the most beneficial impact on soil properties, while with ex situ methods, the use of leaves alone improved soil properties [11]. Marathe et al. [11] applied in situ green manuring through sun hemp (*Crotalaria juncea* L.), and ex situ green manuring through Glyricidia (*Gliricidia sepium*), Karanj (*Pongamia pinnata*) and neem (*Azadiractha indica*) in the pomegranate crop cv. 'Bhagwa'. These authors obtained that maximum decrease in soil pH (6.27) and electrical conductivity (EC) (0.38 dS m^{-1}) was observed in GM with sun hemp treatment, which is attributed to the production of organic acids, namely oxalo-acetic acid and glutamic acid, while the lowering of EC values was ascribed to the increased permeability and consequent salt leaching [11,33]. GM with sun hemp treatments also significatively increases organic carbon content and N in the soil and increases macro-nutrient uptake by pomegranate plants [11]. In addition, this treatment also increases the plant height and plant spread in pomegranate trees.

Otherwise, essential oils such as *Majorana hortensis* emulsion oil (MEO) are emerging as an effective type of eco-friendly product with nematicidal properties [34–37]. An eco-friendly emulsion of marjoram oil (MEO), which was created by combining one volume of MEO (2.5%) with two volumes of surfactant [polyethylene glycol dioleate (non-ionic surfactant) + Toximol (ionic surfactant)] and water, was applied by Hammad and El-Sagheer [28] at a rate of 5000 ppm, three times, to the pomegranate crops cv. 'Altaayifaa', 'Manfaluty', and 'Wonderful' (first, third, and fifth weeks after the inoculation of these crops with nematodes). This treatment increased plant fresh weight by 305.2% and shoot dry weight by 208.0%, in addition to showing a significant effect in the reduction of *M. incognita* by 82.5%.

Maity et al. [38] reported a novel fungal strain known as MCC 0114 (*Penicillium pinophilum*) for pomegranate soil ecology that significantly increased K and P uptake by pomegranate plant. These authors formulated a product of *P. pinophilum* MC 0114 which had a conidial count ranging from 4 to 5 × 1012 CFU g^{-1} formulation capable of storage, distribution and application in the agricultural market. Maity et al. [38] conducted a field study to evaluate the effect of different formulations on nutrient availability, fruit yield, and quality in pomegranate crops. For this objective, these authors performed different treatments: soil inoculated with a bio-formulation of *P. pinophilum*, soil inoculated with the same bio-formulation with the addition of insoluble K (potassium feldspar powder, K_2O 10%) at three different rates (10 g, 20 g, and 40 g K_2O $tree^{-1}$). The bio-formulation was mixed with well-decomposed farmyard manure in a 1:25 ratio, followed by the addition of insoluble K and soil mixing. The authors found that the highest improvement in available K and P content was obtained when the bio-formulation was supplemented with 20 g K_2O $tree^{-1}$ of insoluble K. They also observed that the available K content of soil increased throughout the fruit growth and development period, while the available P content increased up to the fruit development stage and then declined during fruit maturity. Additionally, the use of this bio-formulation and insoluble K resulted in significantly higher available K and P content in the soil compared to the application of soluble potassic fertilizer at recommended doses during all the phenological stages. During the fruit growth and development period, the available K content of soil was observed to continue increasing, whereas the available P content of soil increased only up to the fruit development stage, and then declined again during the fruit maturity stage, as observed by the authors.

On the other hand, in a study conducted by Villa-Ruano et al. [39] on the 'Apaseo' cultivar of pomegranate fruit, they applied ten kilograms of compost that was made from cow manure which was free from hormones and antibiotics. This compost was applied to each tree. Additionally, a microbial consortium, amino acids, and leachate of vermicompost were combined and applied three times during the emergence of foliage, flowers, and fruits. During the fruiting period, the microbial consortium was applied using the drip irrigation system. Although researchers analyzed the quality of the 'Apaseo' pomegranate fruit, they did not provide any information about any potential improvements to the soil quality in their work.

4. Effect of Organic Treatments in Pomegranate Nutritional and Functional Compounds

Application of farmyard manure at the rate of 20 kg tree^{-1} when planting seedling of pomegranate trees cv. 'Bhagwa' increased fruit yield by 22.3%, 105.3% higher than inorganic fertilizers, recording the highest fruit yield together with PM (poultry management) treatment [11]. Mir et al. [14] reported that the combination of vermicompost, farmyard manure, green manure, biofertilizer and fertilizer in different proportions was effective for increasing annual shoot extension. Among the treatments evaluated, the combination of vermicompost (20 kg tree^{-1}), biofertilizer (80 g tree^{-1}), farmyard manure (20 kg tree^{-1}), green manure, and the recommended dose of fertilizer resulted in the greatest annual shoot extension growth (57.03 cm). This increase in growth was attributed to the enhanced nutrient uptake and increased release of growth factors such as auxins, gibberellins, and cytokinin in the root zone facilitated by microbial inoculants in the rhizosphere soils. Other studies have also reported increased N uptake and growth factor release in the root zone [40,41]. This combination of biofertilizers was found to be effective in increasing the percentage of fruit set. This could be attributed to the availability of nutrients in the rhizosphere, which in turn increased the translocation of metabolites from roots to flowers. This, in turn, enhanced pollen germination and pollen tube growth, leading to an increased fruit set [13]. Moreover, increases of fruit yield were also observed after the application of different combinations of these biofertilizers, attributed to strained availability and higher accumulation of N, P, K, and micronutrients in trees. Other authors have reported similar results in guava plant [42,43]. Organic treatments also had an impact on the quality parameters and nutritional content of pomegranate crops. Mir et al. [14] reported that different combinations of vermicompost, farmyard manure, green manure, biofertilizer and inorganic fertilizer markedly improved fruit quality parameters in pomegranate cv. 'Kandhari Kabuli' such as TSS, juice content, titratable acidity, TSS:acid ratio, total sugars, reducing and non-reducing sugars, and ascorbic acid, due to the action of joint application or organic sources and chemical fertilizers. The authors reported that the treatments employed might have acted in a complementary and supplementary manner, improving photosynthetic activity, and allowing for the accumulation of more carbohydrates, starch, and other metabolites, which were then translocated towards pomegranate fruits. Similar results were reported by other researchers who applied a combination of farmyard manure, vermicompost, and biofertilizers, resulting in increased TSS, total sugars, and decreased acidity in pear [44] and apricot [13] crops. These findings were attributed to the positive impact of the treatments on plant total leaf area, leading to increased carbohydrate production through the photosynthesis process.

Marathe et al. [11] reported that applied organic manuring treatments (farmyard manure, vermicompost, poultry manure, and different types of green manure) were significantly effective to improve pomegranate cv. 'Bhagwa' quality in terms of fruit juice, juice acidity, total soluble solids (TSS) and the TSS:acid ratio in fruit juice. Plants supplied with green manure with sun hemp showed the highest juice recovery (44.1%) and TSS (15.8 °Brix), followed by those provided with poultry manure (43.8% and 15.5 °Brix, respectively), in comparison with plants supplied with inorganic fertilizers (43% of juice recovery and 14.6 °Brix). However, the lowest fruit juice acidity and the highest TSS:acid ratio was recorded in vermicompost treatment (0.37% and 40.6, respectively, versus 0.42% and 35.2 with inorganic fertilizer treatment). These authors reported that, in general, juice quality of the pomegranate fruit cv. 'Bhagwa' produced with the application of organic manure was better as compared to inorganic fertilizer [11].

Table 2 displays various organic treatments and their impact on the nutritional and functional compounds in pomegranate crops. In this sense, according to a study by

Hammad and El-Sagheer [28], 'Altaayufaa', 'Manufaluty', and 'Wonderful' cultivars of pomegranate saw a significant increase in fruit yield (162.17%, 135.20%, and 103.18%, respectively) when treated with MEO, chitosan, and vermicompost, compared to the control group. Regarding TSS, MEO showed the highest values of the organic treatments (16.97 °Brix) and chitosan showed the highest content of vitamin C (11.23 mg 100 mL^{-1}). Regarding total protein, MEO provides the highest percentage at 3.92%, followed by chitosan (3.32%) and vermicompost treatments (3.01%). In addition, chitosan treatment resulted in pomegranate juices with 0.32% saturated fatty acid content, while vermicompost treatment yielded juices and fruits with 0.26% saturated fatty acid content, compared to 0.12% in the untreated pomegranate juice fruits (control). These authors reported that nutrient in organic manures that they applied were released slowly and made available throughout the growth period, resulting in better uptake of nutrients, plant vigor, and plant yield. Additionally, these treatments increased microbial population and improved soil physical environment, which facilitated nutrient absorption in a balanced form and translated into increased yield [28]. Other authors have also reported a correlation between yield and an increase in available N, P, and K content with the application of different organic manures, such as green manures and FYM, which have a higher residual effect [45–47].

Abad-Ella et al. [26] found that fruit weight, total soluble solids (TSS), and anthocyanin content in the pomegranate juices of cv. 'Arabi' increased compared to the control (36 m^3 Ha^{-1} of organic fertilizer in the form of sheep manure), while acidity showed an opposite trend. The treatment that showed the best results was 50% of the recommended rate of NPK + 25 g $tree^{-1}$ of humic acid, followed by 50% of the recommended rate of NPK + 12.5 g $tree^{-1}$ and a compost treatment at a rate of 25 kg $tree^{-1}$. Authors attributed improvement in yield and fruit quality of pomegranate cv. 'Arabi' to the synergistic effect of combining organic and mineral amendments, which led to the improvement of soil physical and chemical properties and the availability of nutrients. This, in turn, improved plant growth and fruit production quality [26].

Maity et al. [38] reported in pomegranate crop cv. 'Bhagwa' a significant increase in fruit yield, average fruit weight, hundred arils weight, and juice content when applying bio-formulations of *P. pinohillum*. The fruit yield increased by 35.17% when trees were inoculated, which was significantly higher (27.24%) than the yield obtained by applying the recommended dose of soluble potassic fertilizer. The combination of bio-formulation and insoluble K at a rate of 20 g K_2O $tree^{-1}$ resulted in the highest average fruit weight (257.45 g). Additionally, applying bio-formulation and insoluble K at the rate of 10 g K_2O $tree^{-1}$ yielded the highest aril test weight (hundred arils weight). These authors affirmed that application of this bio-formulation also had an impact on the quality attributes of pomegranate fruit. After the application of this bio-formulation, significant improvement in ascorbic acid, phenol, and sugar content (particularly reducing sugar) was recorded. Moreover, incorporating insoluble K at rates of 10 and 20 g K_2O $tree^{-1}$, combined with the bio-formulation, led to the most notable enhancement in phenol and fruit reducing sugar content. It is noteworthy that the application of this bio-formulation resulted in a significant reduction in non-reducing sugar content, which is not desirable from a human health perspective. Additionally, the content and concentration of K and P in fruits were significantly higher in the fruits of plants inoculated with bio-formulation, showing the greatest results in the trees inoculated with bio-formulation plus insoluble K at the rate of 20 g K_2O $tree^{-1}$. The improvement in ascorbic acid, phenol and sugar concentration might have resulted from the better K and P nutritional fulfillment and their involvement in fruit physiology of pomegranate plant. The authors concluded that using the bio-formulation in conjunction with insoluble K mineral at a rate of 20 g K_2O $tree^{-1}$ had a significantly greater impact, suggesting that combining potassium solubilizing bio-formulation with insoluble K minerals or rocks could completely replace the need for potassic fertilizer in pomegranate cultivation, demonstrating a synergistic effect.

Almutairi et al. [48] applied 100% organic manure containing 0.07 units of P_2O_5, 0.24 units of N, 0.13 units of CaO, 0.07 units of MgO, and 0.27 units of K_2O, which was added at a rate of 19.35 kg tree^{-1} in November of each season. This organic manure contained 22% organic C, 44% organic matter, 0.38% P_2O_5, 1.40% K_2O, 1.24% N, 0.36% MgO, 0.68% CaO, 4500-ppm Fe, 125-ppm Zn, 44-ppm Cu, and 450-ppm Mn, while it had a moisture content of 11.4 db (dry basis) and a C:N ratio of 11:1. This organic manure was applied in combination with mineral fertilizer in different proportions. These authors reported that, except acidity, all of the quality parameters in pomegranate fruits cv. 'Wonderful' were increased with the application of organic manure and the combination of organic manure with mineral fertilizer. In contrast, these authors observed that the application of 100% mineral fertilizer generated lower values for all chemical properties, except acidity, than the values obtained with treatments containing organic fertilizer. Almutairi et al. [48] concluded that co-application of organic and mineral fertilizers produces better quality pomegranate fruits than does the application of mineral fertilizer alone.

The amount of total flavonoids detected by Villa-Ruano et al. [39] was higher in pomegranate fruits harvested under organic conditions (0.44 mg g^{-1}) than fruits harvested under conventional conditions (0.33 mg g^{-1}). This difference between organic and conventional conditions has also been reported by other authors in spinach [49]. These authors also reported that pomegranates harvested under organic conditions also showed higher values of total phenols (2270 mg 100 g^{-1}) than the ones harvested under conventional conditions (1651 mg 100 g^{-1}). The values obtained for organic pomegranates were 40% higher than those of conventional pomegranates. These data suggest that pomegranates grown under organic conditions accumulate more amounts of antioxidants, which have been reported by other authors in kiwifruit [50] and sweet pepper [51]. This fact is related to the oxidative stress that organic fruit experience because of the absence of synthetic pesticides which exert a pressure to biosynthesize antioxidants [39,52]. Another reason for the increase in antioxidants could be the carbon/nitrogen balance. When nitrogen is easily available, the plant will first make compounds with high nitrogen content, such as proteins and secondary metabolites such as alkaloids. However, when the nitrogen availability is limiting for growth, the plant metabolism varies to synthetize more carbon-containing compounds, such as phenolic and terpenoids [53]. Another possibility for the increase in antioxidants would be the growth/differentiation balance hypothesis, which stablishes that the plant will always assess the resources available to it and optimize its investment in processes directed towards growth or differentiation, related in the last case with a greater formation of defensive compounds [53].

Villa-Ruano et al. [39] also reported that, in pomegranates cv. 'Apaseo' grown under organic conditions, the content of galactose, mannose, and sucrose were higher than those obtained by conventional conditions. Regarding sucrose, the samples obtained under organic conditions showed five times higher amounts of this non-reducing sugar than samples obtained by conventional conditions. Other organic crops grown under organic conditions, such as carrots, apples, and cherries, have also shown an increase in the endogenous levels of sugars, mainly in the content of sucrose [53], which can be related to a decrease in invertase activity [39]. Moreover, Villa-Ruano et al. [39] reported that pomegranates obtained by organic conditions showed significantly higher levels of endogenous levels of essential amino acids (histidine, methionine, phenylalanine, threonine, and valine), some non-essential amino acids (tyrosine and proline), and malic and fumaric acids than in those grown under conventional conditions. The same trend was observed in ascorbic acid, which showed slightly higher levels in juices from pomegranate plants grown under organic conditions. This trend had also been detected in other crops grown under organic conditions when compared to those grown under conventional conditions [54,55].

Table 1. Organic treatments and their influence in fruit quality and yield parameters in pomegranate crop.

Treatments	Cultivar	Fruit Yield (kg Plant^{-1})	Average Fruit Weight (g)	Fruit Juice (%)	Juice Acidity (%)	TSS (°Brix)	TSS: Acid Ratio	Reference
Farm yard manure	'Bhagwa'	3.86	146.8	41.5	0.43	15.07	35	[11]
Vermicompost	'Bhagwa'	2.18	145.0	40.8	0.37	15.13	40.6	[11]
Poultry manure	'Bhagwa'	3.96	133.8	43.8	0.41	15.53	38.3	[11]
Green manuring sun hemp	'Bhagwa'	2.97	150.9	44.0	0.44	15.80	36.2	[11]
Green manuring glyricidia	'Bhagwa'	2.38	155.1	43.3	0.42	15.33	36.6	[11]
Green manuring Karanj	'Bhagwa'	2.03	137.7	41.3	0.45	15.20	33.6	[11]
Green manuring Neem	'Bhagwa'	2.75	155.9	43.7	0.46	15.40	33.5	[11]
Vermicompost	'Altaayifaa', 'Manfaluty' and 'Wonderful'	18.53	[a] nd	nd	nd	15.7	nd	[28]
T. asperellum	'Altaayifaa', 'Manfaluty' and 'Wonderful'	16.42	nd	nd	nd	14.17	nd	[28]
Chitosan	'Altaayifaa', 'Manfaluty' and 'Wonderful'	21.45	nd	nd	nd	15.77	nd	[28]
Marjoram emulsion oil	'Altaayifaa', 'Manfaluty' and 'Wonderful'	23.91	nd	nd	nd	16.97	nd	[28]
Nemaphos	'Altaayifaa', 'Manfaluty' and 'Wonderful'	28.36	nd	nd	nd	18.57	nd	[28]
VC20 [b] + NPK (50% recommended dose)	'Kandhari Kabuli'	26.74	375.28	65.93	0.39	14.42	36.97	[14]
FYM20 [c] + NPK (50% recommended dose)	'Kandhari Kabuli'	26.67	365.74	63.72	0.43	14.36	33.40	[14]
VC20 + B80 [d] + FYM20 [e] + GM [f] + NPK (50% recommended dose)	'Kandhari Kabuli'	31.37	409.22	67.09	0.36	15.65	41.95	[14]
VC20 + NPK (75% recommended dose)	'Kandhari Kabuli'	29.12	383.19	66.34	0.39	15.05	38.63	[14]
FYM + NPK (75% recommended dose)	'Kandhari Kabuli'	29.12	380.20	65.47	0.44	14.81	33.66	[14]
VC20 + 80 + FYM20 + GM + NPK (75% recommended dose)	'Kandhari Kabuli'	34.02	419.87	68.43	0.35	16.01	47.30	[14]
VC20 + NPK100 (100% recommended dose)	'Kandhari Kabuli'	29.24	391.74	65.35	0.39	14.94	38.31	[14]
FYM20 + NPK100 (100% recommended dose)	'Kandhari Kabuli'	29.10	389.34	64.57	0.45	14.93	33.18	[14]
VC20 + B80 + FYM20 + GM + NPK (100% recommended dose)	'Kandhari Kabuli'	32.41	415.23	67.84	0.36	15.70	43.63	[14]
VC20 + RDF [g]	'Kandhari Kabuli'	30.73	401.77	66.53	0.40	15.24	38.16	[14]
FYM20 + RDF	'Kandhari Kabuli'	30.73	400.65	66.57	0.45	15.21	34.69	[14]
VC20 + B80 + FYM20 + GM + RDG	'Kandhari Kabuli'	30.62	390.88	66.93	0.37	15.58	14.62	[14]
Compost (25 kg tree^{-1})	'Arabi'	nd	199.3	nd	1.22	13.25	10.86	[26]
Humic acid at 12.5 g tree^{-1}	'Arabi'	nd	207.25	nd	1.21	14.85	12.27	[26]
Humic acid at 25 g tree^{-1}	'Arabi'	nd	214.25	nd	1.12	15.3	13.66	[26]
NPK (50% recommended dose) + compost	'Arabi'	nd	238.5	nd	0.99	17.6	17.78	[26]
NPK (50% recommended dose) + humic acid at 12.5 g tree^{-1}	'Arabi'	nd	241.0	nd	0.93	18.4	19.78	[26]
NPK (50% recommended dose) + Humic acid at 25 g tree^{-1}	'Arabi'	nd	244.9	nd	0.93	18.3	19.68	[26]
Bioformulation of *P. pinophilum*	'Bhagwa'	nd	nd	nd	0.36	13.93	53.57	[38]
Bioformulacion of *P. pinophilum*+ insoluble k (10 g K_2O tree^{-1})	'Bhagwa'	nd	nd	nd	0.33	13.99	42.39	[38]
Bioformulacion + insoluble k (20 g K_2O tree^{-1}) + FYM	'Bhagwa'	nd	nd	nd	0.34	14.19	41.73	[38]
Bioformulacion + insoluble k (40 g K_2O tree tree^{-1})	'Bhagwa'	nd	nd	nd	0.38	14.13	37.18	[38]
100% organic manure	'Wonderful'	nd	nd	nd	1.13	15.81	13.99	[49]
75% mineral fertilizer + 25% organic manure	'Wonderful'	nd	nd	nd	1.32	17.26	14.14	[49]
50% mineral fertilizer + 50% organc manure	'Wonderful'	nd	nd	nd	1.28	16.88	13.18	[49]
25% mineral fertilizer + 75% organic manure	'Wonderful'	nd	nd	nd	1.22	16.45	13.48	[49]

[a] nd = not determined; [b] VC20, vermi-compost: 20 kg tree^{-1}; [c] FYM20, farmyard manure 20 kg tree^{-1}; [d] B80, biofertilizer: 80 g tree^{-1}; [e] FYM20, farmyard manure 20 kg tree^{-1}; [f] GM, green manure; [g] RDF, recommended dose of fertilizer (NPK 100% recommended dose + FYM20).

Table 2. Organic treatments and their influence in nutritional and functional compounds in pomegranate crop.

Treatments	Cultivar	Vitamin C (mg 100 mL^{-1})	Saturated Fatty Acids (%)	Unsaturated Fatty Acids (%)	Reducing Sugars (%)	Non-Reducing Sugars (%)	Tannins (%)	Anthocyanins (%)	Phenol (mg L^{-1} GAE [h])	Reference
Vermicompost	'Altaayifaa', 'Manfaluty' 'Wonderful'	10.50	0.264	0.220	nd [a]	nd	nd	nd	nd	[28]
T. asperellum	'Altaayifaa', 'Manfaluty' 'Wonderful'	10.00	0.202	0.126	nd	nd	nd	nd	nd	[28]
Chitosan	'Altaayifaa', 'Manfaluty' 'Wonderful'	11.23	0.320	0.243	nd	nd	nd	nd	nd	[28]
Marjoram emulsion oil	'Altaayifaa', 'Manfaluty' 'Wonderful'	10.33	0.325	0.295	nd	nd	nd	nd	nd	[28]
Nemaphos	'Altaayifaa', 'Manfaluty' 'Wonderful'	11.66	0.375	0.301	nd	nd	nd	nd	nd	[28]
VC20 [b] + NPK (50% recommended dose)	'Kandhari Kabuli'	12.23	nd	nd	9.46	1.27	nd	nd	nd	[14]
FYM20 [c] + NPK (50% recommended dose)	'Kandhari Kabuli'	12.23	nd	nd	9.16	1.39	nd	nd	nd	[14]
VC20 + B80 [d] + FYM20 [e] + GM [f] + NPK (50% recommended dose)	'Kandhari Kabuli'	15.02	nd	nd	10.92	1.08	nd	nd	nd	[14]
VC20 + NPK (75% recommended dose)	'Kandhari Kabuli'	12.92	nd	nd	9.84	1.44	nd	nd	nd	[14]
FYM20 + NPK (75% recommended dose)	'Kandhari Kabuli'	12.90	nd	nd	9.62	1.53	nd	nd	nd	[14]
VC20 + 80 + FYM20 + GM + NPK (75% recommended dose)	'Kandhari Kabuli'	14.92	nd	nd	11.73	1.04	nd	nd	nd	[14]
VC20 + NPK100 (100% recommended dose)	'Kandhari Kabuli'	13.06	nd	nd	9.72	1.82	nd	nd	nd	[14]
FYM20 + NPK100 (100% recommended dose)	'Kandhari Kabuli'	13.04	nd	nd	9.51	1.84	nd	nd	nd	[14]
VC20 + B80 + FYM20 + GM + NPK (100% recommended dose)	'Kandhari Kabuli'	14.95	nd	nd	11.61	1.06	nd	nd	nd	[14]
VC20 + RDF [g]	'Kandhari Kabuli'	13.60	nd	nd	10.76	1.17	nd	nd	nd	[14]
FYM20 + RDF	'Kandhari Kabuli'	13.58	nd	nd	10.74	1.18	nd	nd	nd	[14]
VC20 + B80 + FYM20 + GM + RDG	'Kandhari Kabuli'	14.99	nd	nd	11.60	1.08	nd	nd	nd	[14]
Compost (25 kg tree^{-1})	'Arabi'	2.15	nd	nd	nd	nd	2.59	0.351	nd	[26]
Humic acid at 12.5 g tree^{-1}	'Arabi'	2.17	nd	nd	nd	nd	2.59	0.349	nd	[26]
Humic acid at 25 g tree^{-1}	'Arabi'	2.18	nd	nd	nd	nd	2.58	0.358	nd	[26]
NPK (50% recommended dose) + compost	'Arabi'	2.19	nd	nd	nd	nd	2.58	0.367	nd	[26]
NPK (50% recommended dose) + humic acid at 12.5 g tree^{-1}	'Arabi'	2.21	nd	nd	nd	nd	2.57	0.374	nd	[26]
NPK (50% recommended dose) + Humic acid at 25 g tree^{-1}	'Arabi'	2.21	nd	nd	nd	nd	2.57	0.375	nd	[26]
Bioformulation of *P. pinophilum*	'Bhagwa'	13.13	nd	nd	13.17	0.76	nd	nd	1386.70	[38]
Bioformulacion of *P. pinophilum* + insoluble K (10 g K_2O tree^{-1})	'Bhagwa'	14.38	nd	nd	13.56	0.43	nd	nd	1536.68	[38]
Bioformulacion + insoluble K (20 g K_2O tree^{-1}) + FYM	'Bhagwa'	14.38	nd	nd	14.10	0.09	nd	nd	1521.93	[38]
Bioformulacion + insoluble K (40 g K_2O tree^{-1})	'Bhagwa'	13.75	nd	nd	13.33	0.80	nd	nd	1378.79	[38]
100% organic manure	'Wonderful'	14.2	nd	nd	12.10	1.02	nd	0.263	nd	[49]
75% mineral fertilizer + 25% organic manure	'Wonderful'	15.85	nd	nd	12.81	1.23	nd	0.293	nd	[49]
50% mineral fertilizer + 50% organic manure	'Wonderful'	15.37	nd	nd	12.63	1.20	nd	0.284	nd	[49]
25% mineral fertilizer + 75% organic manure	'Wonderful'	14.73	nd	nd	12.22	1.08	nd	0.271	nd	[49]

[a] nd = not determined; [b] VC20, vermi-compost: 20 kg tree^{-1}; [c] FYM20, farmyard manure 20 kg tree^{-1}; [d] B80, biofertilizer: 80 g tree^{-1}; [e] FYM20, farmyard manure 20 kg tree^{-1}; [f] GM, green manure; [g] RDF, recommended dose of fertilizer (NPK 100% recommended dose + FYM20); [h] GAE: gallic acid equivalent.

5. Conclusions

Different studies showed that the nutritional requirements of pomegranate crop can be fulfilled with exclusive organic sources. A combination of organic sources with mineral fertilizers reduces the amount of mineral fertilizers needed. In addition, organic treatments improved soil health, growth, and yield in pomegranate crop. In addition, organic treatments in pomegranate crop presented an enhancement in fruit quality parameters, improving nutritional and nutraceutical properties of the pomegranate fruit edible part. Organic pomegranates showed high amounts of sugars, phenols, anthocyanins, valuable amino acids, total flavonoids, and phenolic content. Data of these studies endorsed the fact that pomegranates cultured under organic conditions may have a better fruit quality and nutraceutical content than those grown under conventional conditions. Although the data show that organic conditions improved fruit quality in pomegranate crop, more scientific evidence is needed to establish the potential of organic treatments. Further investigations should be focused on the organic management of pomegranate cultivars in Spain, the main exporter country of the European Union, and that presents a pomegranate protected by a designation of origin, the cultivar 'Mollar de Elche'. In addition, an economic estimation of the cost of the production cost of pomegranate organic cultivation could be essential to gain more knowledge about organic practices and obtain added value.

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