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Review

Effect of Magnetic and Electrical Fields on Yield, Shelf Life and Quality of Fruits

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Abstract: The presented article is a review of the literature reports on the influence of magnetic and electric fields on the growth, yield, ripening, and durability of fruits and their quality. The article shows the potential application of MF and EF in agricultural production. Magnetic and electrical fields increase the shelf life of the fruit and improve its quality. Alternating magnetic fields (AMF) with a value of 0.1–200 mT and a power frequency of 50 Hz or 60 Hz improve plant growth parameters. MF cause an increase in firmness, the rate of maturation, the content of beta-carotene, lycopene, and fructose, sugar concentration, and a reduction in acidity and respiration. The most common is a high-voltage electric field (HVEF) of 2–3.61 kV/cm. These fields extend the shelf life and improve the quality of fruit by decreasing respiration rate and ethylene production. The presented methods seem to be a promising way to increase the quantity and quality of crops in agricultural and fruit production. They are suitable for extending the shelf life of fruit and vegetables during their storage. Further research is needed to develop an accessible and uncomplicated way of applying MF and AEF in agricultural and fruit production.

Keywords: electrical fields; magnetic fields; high-voltage electric field; growth of fruits; ripening of fruits; shelf life of fruits

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1. Introduction

Magnetic and electrical fields occur in the environment and constantly affect living organisms and affect the course of many biological processes [1]. All plants live and develop in the presence of the Earth's magnetic field and the electrical field that occurs between clouds and the Earth [2]. The Earth's magnetic field is mainly produced by the dynamo action of turbulent flows in the fluid metallic outer core of the planet [3]. MF is related to the movement of electrical charges. There are differences on the ground in the strength and direction of the Earth's magnetic (geomagnetic) field. The vertical component of this field is at a maximum at the magnetic pole (about 67 μT) and is zero at the magnetic equator, while the horizontal component is at a maximum at the magnetic equator (about 33 μT) and is zero at the magnetic poles [4]. An electric field is produced by stationary charges [5]. Shawanroy (2012) noted that the combination of an electric field and a magnetic field can be viewed as an electromagnetic field (EMF) [6]. One of the sources producing an electromagnetic field is high-voltage power transmission lines, which may affect the growth of plants and selected crops. A magnetic field (MF) is a source of energy, thereby it has effects on the metabolism of cells [7] and has an impact on meristem cell division [8]. In addition, an MF affects water absorption, preservation, and ionisation [9]. It may cause magnetophoresis in macromolecules [10] and an increase in the chemical reactions of plants, causing a positive effect on photochemical activity, respiration ratio, and enzyme activity [11,12]. This same stimulation of plants with a magnetic field is a way to increase the quantity and quality of seed germination, seedling development, and yields of different species, such as field, fodder, and industrial crops, herbs, and medicinal plants [5].

In addition, yield improvement can be achieved with a pre-sowing treatment of seeds with electrical and electromagnetic fields [12–14]. Research studies have shown that a high-voltage electric field (HVEF) can be used to maintain the freshness of food by extending its shelf life, improving product quality and inhibiting microbial growth [15–17]. It is classified as a non-thermal and low-energy treatment. The HVEF process is based on the production of an electrical wind by corona discharge between at least two electrodes. Different electrode configurations, such as point-ring, needle-ring, needle-plate, and wire-plate, are commonly used for preparing the electrical field. The ions produced in a small area around the needle electrodes are then accelerated by an electrical field. Corona discharge involves the partial electrical breakdown of the gaseous medium [18,19]. Research has illustrated that outer electrical and magnetic fields impact on the actuation of ions, polarisation of electric doublet, water absorption, preservation, and ionisation [9,20]. Many studies have shown that magnetically activated water used in agriculture helps improve germination, plant growth, flowers, fruit, and crop yield. Magnetic treatment of water enhances the overall physical characteristics of the fruit and water productivity [21–23].

Fruit is essential in human nutrition and health and it contains a very high percentage of water compared with other plant-derived foods, such as seeds. Therefore, they exhibit relatively high metabolic activity after harvest and, in consequence, this leads to the rapid breakdown of the structure of the fruit and the loss of its properties [24]. During fruit ripening, many physiological and biochemical processes take place in their cells. These processes result in changes in the colour, taste, and texture of the fruit [25]. These features determine the acceptance of the fruit by the consumer [26]. During ripening and storage, the fruit softens and loses its hard texture [27]. The rate of change is genetically programmed, but also influenced by environmental factors [28]. The strength of fruit tissues, and thus the stability of the whole fruit, is influenced by the mechanical properties of the cell walls, the presence of intercellular fluid, and intercellular interactions in the middle lamina [29]. These factors are subject to changes and constant modifications during the ripening of the fruit. The cell wall is responsible for the physical endurance and shape of the cell [30]. The properties of the cell wall are determined by cell size, inter-cell adhesion, packing and turgor, wall thickness, wall composition, and cell response to shear stress [29]. Most often, plant cell walls on a dry weight basis contain 15–40% cellulose, 30–50% pectin polysaccharides, 20–30% xyloglucan, and smaller amounts of other hemicelluloses and structural proteins [27]. The structure of the cell walls is constantly changing during the growth and storage of the fruit. The main factor responsible for the properties of the cell wall, i.e., stiffness, porosity, and interactions between cells, are pectins [31]. Fruit texture involves a series of alterations in the cell wall, which are genetically programmed, but is also influenced by environmental factors. Pectinase (PE) is involved in the degradation of pectins [32], and thus leads to the degradation of the cell wall. This has a negative effect on fruit firmness [33,34]. Fruits are classified by their respiration profile and ethylene production as climacteric and non-climacteric ones. Climacteric fruits include tomato (*Solanum lycopersicum* L.), banana (*Musa acuminata Colla*), apple (*Malus domestica*), mango (*Mangifera indica*), and pear (*Pyrus amygdaliformis*), while grape (*Vitis vinifera*), citrus (*Citrus medica*), and watermelon (*Citrullus lanatus*) belong to the non-climacteric class [35]. Ethylene is closely associated with these changes in climacteric fruits [36,37], but its role cannot be excluded in the softening of non-climacteric fruit [38–41].

The purpose of this paper is to review scientific results and summarise the emerging topic of the effects of magnetic and electrical fields on the growth, yield, ripening, and shelf life of fruits and on fruit quality, as well as the potential application of MF and EF in agricultural production.

The characteristics of the data presented take into account the following variable factors: variety, method used, field intensity, and time of exposure. Treatment with magnetic and electrical fields has been applied in the whole plant production system, namely on the pre-treatment of seeds and the treatment of seedlings, plants, and fruit and of irrigation water.

2. Effect of Magnetic Fields and Electrical Fields on the Growth, Development, and Yield of Fruit

Research work on the effect of MF on the growth, development, and yield of fruit is reviewed and summarised in Table 1. The results obtained are divided into the following areas depending on the intensity of the magnetic field and the duration of exposure to it: seed and seedling treatments, plant treatment, water irrigation, and water treatment.

Table 1. Summary of the total effect of magnetic fields on the yield and growth of fruit.

Variety	Method	MF Parameter	Effect	References
Tomato *Campbell 28*	Seed treatment	90 mT for 10 min 154 mT for 3 min MF	Increase in leaf area, leaf dry weight, SLA in growth rate of stem and roots, enhanced mean weight, diameter and yield of fruit	De Souza et al., 2006 [42]
Tomato *Vyta*	Seed treatment	120 mT for 10 min 80 mT for 8 min LFMF	Increase in root and stem length, fresh dry root, and dry stem weight, mean fruit weight and fruit yield	De Souza et al., 2005 [43]
Tomato *Lycopersicon Esculentum* L.	Seed treatment	Static MF 50, 100, 150 mT for 1 h	Increase in plant height, shoot and root weight, and dry weight of plant, also improved and enhanced tomato growth parameters: number of leaves/plant, leaf area, number of flowers/plant, number of fruits/plant	Kutby et al., 2020 [44]
Tomato *MST/32*	Seed treatment	MF 332.1; 108.7; 50.6 mT for 1, 2, 24 h	Increase in speed of germination, stem weight ratio, the longer the exposure to MF, the higher the accumulation of biomass in the leaves and stem	Poinapen et al., 2013 [41]
Tomato *Pusa Rohini*	Seed treatment	Static MF 100 mT for 30 min	Increase in speed of germination, reactive oxygen species (superoxide and hydrogen peroxide), activities of antioxidant enzymes, relative expression of various genes in germinating tomato seeds and decrease in total antioxidant capacity	Anand et al., 2019 [45]
Tomato Onion (*Allium cepa* L.)	Seed treatment	Static MF generated by a coil	Increase in weight and yield	Kireva, Mihov 2018 [46]
Tomato	Seed are harvested from plant and are induced by MF and infected by *Fusarium* sp. monospore suspension	MF 0.2 mT for 7 min 48 s, 11 min 44 s, 15 min 36 s	Increase in germination % and rate, dry weight	Agustrina et al., 2018 [47]

Table 1. *Cont.*

Variety	Method	MF Parameter	Effect	References
Melon (*Cucumis melo*): *Ravi*	Seed treatment	MF 100, 200 mT for 5–20 min	Increase in germ germination, root and shoot extents, vigour indices, plantlets fresh and dry mass, leaf region, alpha amylase, protease, catalase, chlorophyll	Iqbal et al., 2016 [48]
Passion fruit (*Passiflora edulis Sims*)	Seed treatment	Static MF 200 mT during germination test 14 days	Increase in germination speed index, germination %, emergence speed index	Menegatti et al., 2019 [49]
Sesame (*Sesamum indicum* L.): *Winas*	Seed treatment	MF from 2 parallel coils 0.1–0.5 mT for 20 min every day for 5 days	Increase in stem height, chlorophyll content, fruit weight and resistance to *F. oxysporum*	Tirono et al., 2021 [50]
Tomato (*Solanum lycopersicum* L.)	Seedling treatment	MF 1–3 mT for daily exposure	Increase in chlorophyll level with low MF and exposure time	Răcuciu 2020 [51]
Strawberry (*Fragaria × ananasa*) *Camarosa*	Plant treatment with electric wire	MF 96, 192, 384 mT	Increase in fruit yield, average fruit weight, number of leaves, fresh and dry root weight Expansion in macroelements and Zn content of plant leaves	Eşitken, Turan 2003 [52]
Strawberry *Camarosa*	Plant treatment with electric wire	MF 96, 192, 384 mT	Increase in fruit yield, average fruit weight, quantity of leaves, fresh and dry root scale Increase in N, K, Ca, Mg, Fe, Mn, and Zn content of plant leaves	Eşitken, Turan 2003 [52]
Strawberry *Camarosa* Tomato *Micro-Tom*	Treatment of culture medium	Magnet NdFeB	Increase in the number of leaves, shoot and root fresh weight, root and shoot length and chlorophyll content and Mg, Ca, Fe, K, P, and Na uptake	Taimourya 2017 [53]
Banana *Williams*	Magnetically treated irrigation water	Device with magnets up to 136 mT	Increase in fruit length, weight and yield	El-Kholy et al., 2015 [54] Patil 2014 [29]
Tomato	Irrigation water magnetised	MF 12.4 31.9 71.9 mT	Increase in stem diameter, height of tomato plant and yield of tomato	Yusuf, Ogunlela 2015–18 [55,56]
Mandarin (*Citrus reticulata*) *Balady Fremont*	Treatment of trees with magnetic water	Two magnets 3.5–93 mT	Increase in pulp and peel weight of fruits and yield	Taimourya et al., 2018 [57]
Strawberry *Camarosa*	Magnetically treated irrigation water	MF in the range of 3.5–136 mT	Increase in number of flowers, fruits, yield and quality of fruits	Taimourya et al., 2018 [57]

Table 1. *Cont.*

Variety	Method	MF Parameter	Effect	References
Tomato *Pavlina*	Treatment of seeds and plants	MF for 50 Hz 20, 40 and 60 mT for 20 min seeds and plants for 48 days	Increase in seed germination, growth of young plant, size of fruit, stem length, weight of tomatoes and earlier fruit setting	Jedlička et al., 2015 [58]
Tomato *Castlerock*	Seed treatment with distilled water and irrigation with magnetised water	MF 0.1; 0.15 and 0.2 T for 1, 5, 10 and 15 min	Optimal magnetic treatment 0.1 T for 15 min, increase in stem length and diameter, Leaf area and fresh and dry weight	El-Yazied et al., 2011 [59]
Tomato *Rocco* and *Monza*	Seeds Seedbed plots, Irrigation with magnetised water	MF 4–6 mT for 2.5 s—seeds 3 times -seedbeds 3 movement—plots	Yield increased on *Monza* 28–51% and bloomed 3–4 days earlier	Danilov et al., 1994 [60]
Tomato *Castlerock*	Seed treatment Irrigation with magnetised water	MF 10 mT for 10 min Magnetic field treatment of water 80 mT	Increase in height, yield and fresh weight, P mineral content in plant leaves	El-Yazied et al., 2012 [61]

2.1. *Effect on Germination*

Many studies show that a magnetic field has a positive effect on seed [27,40,41].

The strength of the MF and exposure time are among the most significant factors influencing seed germination, emergence rate, and seed yield [62]. There were significant interaction effects of strength of magnetic field and the duration of exposure on germination percentage [59]. The highest value was noted when seeds were treated with a strength of 0.1 Tesla for 15 min. By contrast, the lowest germination percentage was at an exposure of 0.2 Tesla for 15 min. Similar results were obtained by Souza et al. (1999) with an exposure time of 10 min [63]. Magnetic treatment can accelerate plant emergence by 2–3 days, compared with control plants [63]. El-Yazied et al. (2011) and Aladjadjiyan (2012) showed that the MF dose and the duration of exposure can affect the germination traits of different seeds, including tomato and broad bean. They demonstrated that the strength of MF plays a significant role in germination percentage [59,64]. Poinapena et al. (2013) observed a germination that was approximately 11.0% stronger in magnetically exposed seeds than in unexposed seeds, although the seedlings emerging from the SMF treatments did not show a constant increase in biomass accumulation [41]. They confirm that longer seed exposure (24 h) resulted in better germination, and that shorter exposure (1 and 2 h) resulted in faster germination [40].

The germination rate is an indicator of the metabolic advance of germination events in the treated seeds. In magnetoprimed seeds, the germination rate was 30.3% higher than in unprimed seeds [45]. The results of Agustrina et al. (2018) show that 0.2 mT MF induced parental tomato seeds to yield F1 seeds that have a higher percentage germination rate and dry weight than control tomato parental seeds. A magnetic field of 0.2 mT was applied for 7 min 48 s. [47].

Scientists report that exposure of tomato seeds to magnetic fields may lead to a significant improvement in the growth and development of plants produced by them [41]. This improvement induced by the magnetic treatment was also consistent with the results of other studies [65] that also report enhanced root and stem growth and fresh weight in tomato plants. Socorro et al. (1999) also reported a positive effect of magnetic treatment on leaf thickness in crop tomatoes, leading to a noticeable increase in the thickness of the spongy tissue, and in the length and width of chlorophyll-containing cells and the upper and lower epidermal cells [66]. Research has reported that magnetic treatment of tomato seeds resulted in a significant increase in leaf area, leaf dry weight, average weight of the fruits, as well as an increase in the harvest of tomatoes per unit area [42,43,58]. Iqbal et al. (2016) showed that MF pre-sowing treatment of melon seed enhanced germination by 14.6%, root and shoot lengths by 36.4 and 22.8%, vigour indices I and II by 40.6 and 28.8%, seedling fresh weight by 9.6%, and dry mass by 12.9%, leaf area by 50.0%, alpha amylase by 80.0%, protease by 92.5%, catalase by 36.5%, and chlorophyll "a" and "b" content by 50.4 and 80.9% when compared to control treatments [48]. Fruit yield per plant was also significantly influenced by magnetic treatment, with increases of 19.4–28.5% when compared with controls [42,66,67]. Moon and Chung (2000) confirmed higher mean fruit weight of tomatoes, as well as overall higher yields, in experiments with magnetically treated seeds of tomatoes [27]. Similar effects have been reported on strawberry yield parameters by Esitken and Turan (2004) [68].

Treatment with a magnetic flux density (MFD) from 0.1 mT to 0.3 mT made sprouts grow faster, increased stem height and chlorophyll content, shortened flowering time, and resulted in heavier fruit weight than control treatments [50]. A study by Fu (2012) reported that treatment with an MFD of 0.33 T increased plant height from 4.18 cm to 5.25 cm at four weeks of age [69]. Chlorophyll content is closely related to plant health, with higher chlorophyll content being associated with better plant health [70].

Răcuciu (2020) and Taimourya et al. (2017) showed that the exposure of plants to a magnetic field increased the chlorophyll levels with low magnetic flux density and short duration of exposure, respectively [51,57]. Given that chloroplasts have paramagnetic properties, the influence of magnetic field on plants increases its inner energy, which is distributed among the atoms causing accelerated metabolism [71].

The MF affected various plant characteristics, such as germination of seeds, root growth, rate of seedling growth, reproduction growth rate of the meristem cells, and quantity of chlorophyll [72]. The researchers have shown that the magnetic field changed the characteristics of the cell membrane, causing some changes in cell metabolism. The magnetic field affected various plant properties, such as gene expression, protein biosynthesis, and enzyme activities, and affected various plant functions in either plant organs or tissues [73,74]. The mechanisms of action are represented in Figure 1.

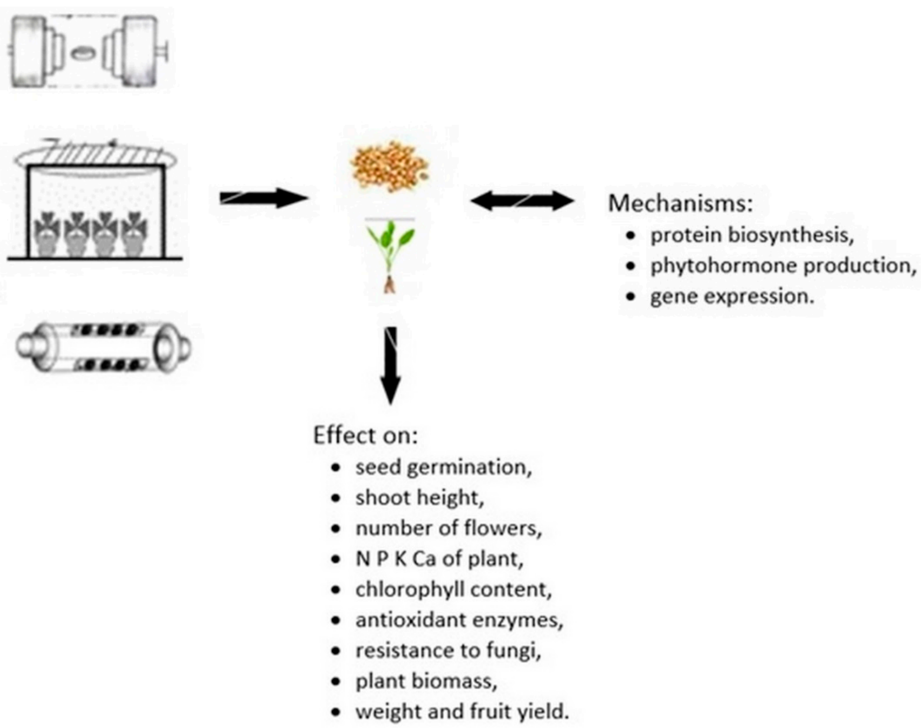

Figure 1. Magnetic field affecting the morphophysiological properties on a fruit plant with possible mechanisms.

2.2. Effect on Plants

Esitken (2003) treated whole strawberry plants with an MF. He showed that increasing MF strength to 0.096 T increased fruit yield per plant by about 18%; however, higher field values reduced fruit yield and had a negative effect on plant growth [52]. All the MF strengths expanded average fruit mass compared with the control, even though the largest fruits of about 8.92.g were set on at 0.096 T. On the other hand, MF had beneficial effect in terms of number of leaves, and fresh and dried root heaviness. Tomato plants cultivated in magnetic treatment by Taimourya et al. (2017) also showed significant increases in the number of leaves, shoot length, and root length, with an increment of 152.9% in number of leaves, 14.4% in shoot length, and 23% in root length [53]. These results are in line with those of De Souza et al. (2006) who observed that pre-treatment of seeds with magnetic field or irrigation with magnetic treatment increased leaf, stem, and root fresh and dry weight of tomato [42]. The same results were confirmed by Eşitken and Turan (2004) [68]. Additionally, they stated that an increase in strength of the MF up to 0.384 T increased the concentration of macroelements and Zn of flora leaves. However, it decreased contents of P as well as S compared with the control. It was similarly reported by Matsuda et al. (1993) that MF had a beneficial effect on crop in strawberry [75]. In shoots of strawberry plants cultivated in a culture medium subject to magnetic treatment, Taimourya et al. (2017) observed an increase in magnesium content by 26.8%; calcium content by 30.2%; iron content by 62.4%; potassium content by 25.3%; phosphorous content by 12.8%; and sodium content by 26.9% [57]. In roots, mineral uptake was increased by 36.6% for magnesium; 23.1% for calcium; 184.8% for iron; 19.3% for potassium; 32.2% for phosphorous; and 58.9% for sodium. Jedlička et al. (2015) stated that there was a positive effect from treatment of young plants of the tomato variety "Pavlina" with magnetic fields of 40 mT. The mean weights of the ripe fruit and the aboveground parts were higher on average by 55.2% and 11.2% than the control variant, respectively [58].

Many studies report the positive effects of treating young plants with a magnetic field. The use of appropriate magnetic field values increases plant growth and crop yield. However, the use of high field values reduced fruit yield and had a negative effect on plant growth.

2.3. Effect of Magnetised Irrigation Water on Plant Growth and Crop Yield

Magnetised aqua is obtained by volatile water across a magnetic field (constant magnets or else electro magnets) in a supply pipeline. A literature overview relates to the beneficial effects of irrigation with magnetised water [61]. Grewal and Maheshwari (2011) reported that some transformation was performed in the physical and chemical features of water because of magnetic treatment [76]. These are mainly related to hydrogen bonding, polarity, surficial tension, conductivity, and pH, as well as dissolubility of salts. Magnetic water has a lower surface tension; therefore, nutrients are more readily absorbed in the water [77,78]. The mechanism in which the magnetic field operated was linked by Phirke et al. (1996), Turker et al. (2007), Maheshwari and Grewal (2009), and Hozayn and Abdul Qados (2010) to the activation of phytohormones, such as gibberellic acid equivalents indole-3-acetic acid and trans-zeatin, and the activation of the bio-enzyme systems leading to improved cell activity and plant growth [30,79,80]. This observation is consistent with the work of De Souza et al. (2005) and Dhawi (2014) that magnetic water accelerates the reactions of enzymes related to auxin (plant hormone), which could increase the growth rate and promote fruit ripening [43,81]. Stange et al. (2002) stated that electromagnetic fields improve the rate of ion shipping through the plasma membrane and influence the structure of the cellule membrane lipid protein and may result in changes in the permeability of the plasma membrane [82]. The results of Yusuf and Ogunlela (2015) revealed that the use of magnetic flux densities of 124, 319, and 719 G for treating the irrigation water caused tomato plants to grow faster and influenced their vegetative growth and stem diameter [55]. This confirms the work of El-Sayed and Sayed (2014) [83]. Taimourya et al. (2018) found that, when using magnetic irrigation water on strawberry plants, there was a boost in the amount of fruits and fruit crop by over 30% [57]. Fernandez et al. (1996) reported that seedlings developed with magnetically treated irrigation were over 100% higher than the control [84]. In a nursery experiment, El-Yazied et al. (2011) applied the optimal magnetic seed treatment of tomato (0.1 T for 15 min) and/or irrigated with magnetised water. This produced significant increases in transplant stem length, stem diameter, leaf area, and fresh and dry weight than those in the control treatment [59]. These results are consistent with those of Grewal and Maheshwari (2011) who reported that tomato grain (cultivar Castle Rock) treatment with a magnetic field of 100 gauss for 15 min, as well as with magnetically treated hydrated water, boost their vegetable rise. Furthermore, treatment increased the total phosphorus component of tomato leaves, as well as total yield, while reducing the pH valuation in soil extraction [76]. In addition, this study revealed that irrigation with magnetically treated water increased nutrient mobility in soil and enhanced extraction and uptake of P, K, N, and Fe by plants [28,53,77,85]. The interaction between aqua treatment and grain treatment, as well as NPK levels, was also tested. The highest valuation of P and the lowest concentrations of Na in tomato leaves were observed with 100 or 75% treatments of NPK fertiliser combined with magnetised seeds and irrigating water [76]. Mohamed (2013) and Ajitkumar (2014) found that magnetic aqua significantly boosts fruit dimensions, the fresh and dry weights of fruits, as well as crop yield compared with a control variant [29,78]. Hamdy et al. (2015) irrigated Balady and Fremont mandarin trees with magnetic water during the growth season and demonstrated a significant increase in yield of nearly 35% in comparison with the control [86]. Yusuf et al. (2018) confirmed an increase in tomato yield with magnetic irrigation water. The percentage increments in tomato yields were 39.9 and 68.7% with magnetic flux densities of 124 and 719 G, respectively. They also showed increased concentrations of calcium, potassium, sodium, nitrogen, phosphorus, and organic carbon when water was treated [56]. Changes in water properties by magnetic fields can alter the characteristics of plant growth and production. Many researchers have concluded that magnetic treatment of irrigation water increases plant growth and crop yield [16,30,61,80,87–90].

2.4. Effect of Magnetic Fields and Electrical Fields on the Ripening and Shelf Life of Fruits

A summary of the effect of MF and EF on the ripening and shelf life of fruits is presented in Table 2.

Table 2. Summary of the total effect of magnetic fields and electrical fields on the ripening and shelf life of fruits.

Variety	Method	MF Parameter	Effect	References
Apples *Melrose*, *Champion*, *Cortland*	Fruit treatment	SPMF 200 mT within storage exposure time 5 × 30	Change in firmness depending on variety, increase in *Melrose* decrease in *Champion*, no change in *Cortland*	Puchalski 2001 [91]
Tomato *V.R Moscow*	Fruit treatment	MF 60 mT within ripening period (15 days)	Increase in ripening rate, beta carotene and lycopene, sugar concentration and decrease in acidity and respiration rate	Boe et al., 1968 [92]
Tomato *Starbuck*	Fruit treatment	MF 2.5 mT for storage period	Low MF did not influence ripening, no significant differences in colour, firmness, lycopene concentration	Bourget et al., 2012 [93]

Table 2. *Cont.*

Variety	Method	MF Parameter	Effect	References
Strawberries *Bogota, Elkat, Ventana, Honeyoe, Salut*	Fruit treatment during vegetative period on plants	SPMF 5–100 mT, AMF 50–150 uT and 5–100 mT for 5 min with 5 replicates each 5 days	Increase in firmness with AMF for 50–150 uT up to 30%	Zaguła et al., 2010 [94]
Apple *Jonagold*	Fruit treatment with compensated vertical component of Geographic MF	Near null GMF after 4, 5 and 6 weeks of storage	Increase in storage time by slowing down the process of enzymatic decomposition of starch and intensity of respiration. Lower content of simple sugars, ash and greater calorific value, volatile compounds and water content were recorded	Zaguła et al., 2020 [95]
Apples *Fuji, Rome Beauty, Golden Delicious* and *Starking Delicious*	Fruit treatment using needles as the cathode and an aluminium plate	EF 1.25–2.5 kV/cm for 1 and 2 h period	Increase in soluble sugar concentration, and decrease in CO_2 production, it becomes tougher and stiffer material	Atungulu et al., 2003 [96]
Apples *Fuji, Sansa, Starking Delicious* and *Golden Delicious*	Fruit treatment with two parallel aluminium plates or needle and plate	EF 3; 3.75; 6 kV/cm EF continuous for week and intermittent 3 h every 5 days	Decrease in CO_2 evolution during storage, and suppressing CO_2 evolution at the peak of the climacteric. Direction of electric field with parallel plate electrode influenced apple respiration	Atungulu et al., 2004 [97]
Apple *Fuji* Pear *culta Nakai* Plum *Karari* Banana *Cavendish*	Fruit treatment with Cu wire and plate (post and pre-climacteric period depending on variety)	EF 4.3 kV/cm for 5 and 20 min	Decrease in respiration rate of fruit	Kharel et al., 1996 [98]
Cherry tomato	Fruit treatment before storage with parallel plates	EF 1, 2, 3 kV/cm for 1 or 2 h	Decrease in fruit weight loss, fruit softening percentage, peak of climacteric delayed by 3 days	Kusuma et al., 2018 [99]
Emblic fruit (*Phyllanthus emblica* L.)	Fruit treatment with 2 copper plates	(AC) and (DC) current ((HVEF) of field strength 4.3 kV/cm for 2 h	AC HVEF can be used to extend the shelf life of emblic fruits, rotting significantly decreased after 25 days storage	Bajgai et al., 2006 [23]
Peach fruit (*Prunus persica*)	Fruit treatment with corona discharge producing ozone within the chamber	EF with voltage 7 kV Within storage	Increase in fruit hardness, decrease in soluble solid content	Shiina et al., 2009 [100]
Persimmon fruits (*Diospyros kaki*).	Fruit treatment between two plates	EF field of 6 kV/cm for 30, 60, 90 or 120 min, 6 duplicates, before storage	Decrease in rate of weight loss, rate of decrease in hardness, rate of carbon dioxide production	Liu et al., 2017 [101]
Tomato *Chaoyan-219*	Fruit treatment with two stainless steel plates used as cathode or anode	EF +/−1, +/−2, +/−3 kV/cm for 2 h within 20 days of storage	Decrease in respiration rate and ethylene production and extending postharvest life by about 7–10 days. HVEF may delay the decline in firmness and the change in colour, total soluble sugar and titratable acidity of fruits	Wang et al., 2008 [102]

Table 2. *Cont.*

Variety	Method	MF Parameter	Effect	References
Tomato *Chaoyan-219*	Fruit treatment with 2 stainless steel plates	EF +/−2 kV/cm for 2 h	Lower production rate of O_2—and the content of H_2O_2, efficient in hold up ripening, as well as the aging process	Zhao et al., 2011 [103]
Mini-tomato (*Lycopersicon esculentum*) *Chika*	Fruit treatment using needles or an aluminium plate as the cathode	EF 1, 2, 3, 4 kV/cm 2 h per day within storage temperature (0–17 C)	Decrease in respiration rate and increase in moisture loss using needle cathode	Atungulu et al., 2005 [104]
Strawberries	Fruit treatment using multiple pin-to-plate electrodes	EF 3.61, 4.56, and 5.13 kV/cm for 1 h	Decrease in mass losses in fruit and extended cold storage and preventing growth of *Botrytis cinerea*	Esehaghbeygi et al., 2021 [105]
	Fruit treatment with glass plate and Cu wire or Cu plate	EF 0.71–4.3 kV/cm for 0.5–1.5 h and continuous	Increase in shelf life of fruits without affecting major chemical constituents. In the 6 days of storage, reduction of fruit rotting by about 80%	Kharel and Hashina 1996 [106]

The effect of magnetic and electrical fields on the postharvest physiology of fruits is a new and a not yet exhausted area of research. Metabolic activity continues after harvest of fruits, thus making most types of fruit highly perishable commodities. As the fruit ripens, respiration increases and their flesh begins to soften and will reach senescence [24,107–109].

Boe and Salunkhe (1963, 1968) reported that a magnetic field exerted a positive effect on the ripening of fruits [92]. MF brought forward the ripening rate of tomato fruit. This acceleration was manifested in increased colour development. The increase in colour development was due to accelerated synthesis of carotenoids, beta carotene, and lycopene. The fruit ripened in the magnetic field also showed characteristic changes in acids and sugars that accompany ripening [92]. However, Bourget et al. (2012) showed that MF, at the low doses used in these experiments, did not influence the ripening of tomato fruit during storage at 16 °C. No significant difference was observed in colour change and weight loss between control and magnetic-field-exposed fruit. Lycopene concentration, firmness, and membrane permeability were also no different between the control and exposed fruit. It was concluded that a higher intensity of magnetic field may be necessary to have an impact on the ripening behaviour of tomatoes [93]. Puchalski (2001) stated that a strong magnetic field of 200 mT boosts the firmness of Melrose apples and, as a result, the storage period was extended by 20 days. However, in the case of the Champion variety, a field of this value was destructive [91]. Valentinuzzi (1964) stated that magnetic fields could be inhibitory in nature because of the reduced incidence of molecular collisions due to the orientation of paramagnetic molecules [107].

Treatment with a strong electrical field has been, in theory, used as a method of foodstuff preservation because of its skill to sterilise microbes, as well as inhibit the activity of enzymes engaged in the loss of food property [22,109–111].

Literature reports that high voltage electrostatic field (HVEF) treatments affect both the physical and biochemical properties of food. Murr (1963) proved that field action connected with the polarisation of organic radicals in the flora biosystems and molecular fatigue can affect the reactions of plants [112]. This results in the maintenance of the postharvest quality of some fruits and the extension of the shelf life of the product [23,96–98,102,106,113–116]. Studies indicate that electric fields cause gas ionisation in room conditions, which then moved towards the opposite electrode at a high velocity. It is a nonthermal treatment useful in extending the shelf life of fruits [23], which impacts the cell membrane permeability and influences enzyme activity and the inhibition of microbial action [103,109,111,113,117]. A corona electrical field might help reduce decay and spore production in stored materials [105]. Kharel and Hashinaga (1996) applied an external electrical field to observe a reduction in the decay rate of strawberries [106]. HVEF treatment of cranberries enhanced the fruit's shelf life [114]. A study by Esehaghbeygi et al. (2021) showed that HVEF at 4.56 kV·cm^{-1} was capable of controlling fungal infections, preventing the growth of *B. cinerea* in treated strawberries, conserving the fruit's moisture content and freshness, and extending the strawberries' storage time [105]. Yu et al. (1995) found that electron beam irradiation suppressed fungal growth on fresh strawberries, with an extension of their shelf life [118].

Atungulu et al. (2005) applied different methods relating to high-voltage treatment to examine their effect on tomato storage [104]. They noted that weight loss in fruit depended on the electrode configuration used. Using needle electrodes as the cathode in the high-voltage treatment (10 kV, 20 kV, and 30 kV) resulted in greater moisture loss than in the untreated samples [104]. Another study compared the use of different methods with electric field direction on the postharvest treatment of apples [97]. Using parallel plates, the arrangement in the "reversed" electric field treatment gave higher weight loss than in the "forward" electric field treatment (apples on an anode plate). However, in corona discharge this process was reversed [97].

Electrostatic treatment is a low energy, nonheated treatment technology and may be influenced to maintain a specific respiration rate for specific fruits and vegetables. Expanding the shelf life of the fruit is possible through curtailment and lag of the respiration of fruits resulting off the containment of ethylene generation [102]. Wang et al. (2008) found that a negative high-level treatment electrostatic field (−2 kV/cm) treating, with its capability to upgrade respiration and ethylene out-turn, can daff tomato fruit maturation and prolong postharvest life during storage for about 7–10 days [102]. Kharel and Hashinaga (1996) stated that a high-voltage electric field (430 kV/m) treatment of pears, plums, and bananas in the preclimacteric period suppressed the respiration rate during the climacteric period. Similarly, little effect on the respiration rate was also observed in apples treated by HVEF in a postclimacteric period [98]. The physicochemical properties (i.e., Brix, pH, hardness, and Hunter "Lab" values) of bananas 17 days after HVEF treatment indicated that HVEF treatment retarded ripening (1.5–2 days) as compared to the control. However, the ethylene production rate in apples and bananas was not affected by a HVEF. The ripening of mature green bananas and sweet peppers was delayed by the exposure of HVEF [98]. Kusuma et al., 2018 found that the climacteric peak for tomatoes was delayed for 3 days in all HVEF pre-treatments at 2 kV/cm applied for 2 h [99]. Wang et al. (2008) assumed that treatment of a −2 kV/cm electrostatic field can efficiently avoid the decrease in firmness and colour progression in tomato fruit, while similar effects were not monitored in fruit treated with a positive electrostatic field. The pitch of respiration as well as ethylene generation of tomato fruit during storage were lagged by 6 days [102]. Wang at al. (2008) and Zhao et al. (2011) confirmed the earlier observations that ethylene output of tomato fruits treated from HVEF was lower before that of the control fruits and that a negative HVEF treatment can inhibit the production of ethylene more efficiently than a positive HVEF treatment [102,103]. However, Shivashankara et al. (2004) demonstrated that a positive high-voltage electrical field (1.5 kV/cm) pre-treatment had an effect on the respiration and antioxidant capability of mango fruit, though did not have some prominent effect on firmness and rind colour of mango fruit. HVEF can also affect the inhibition rate of carbon dioxide, indicating that it has the ability to inhibit metabolism and delay organisational deterioration [119]. Atungulu et al. (2004) found that, after 21 and 39 days in storage, apples treated with 36 and 48 kV showed a lower amount of CO_2 than samples in a non-reversed electric field [97]. In another study, it was shown that 1- or 2-h treatment periods at 10 and 20 kV reduced respiration in apples [96]. Other research showed that an uncompensated geomagnetic field may have an effect on the inhibition rate of carbon dioxide during storage of Jonagold apples. The difference between treated and control samples was 20 mg per kg of fruit in storage [97].

The literature reports that a magnetic field of appropriate intensity accelerates the rate of fruit ripening. The magnetic field accelerates the synthesis of carotenoids, beta-carotene and lycopene. The ripening of the fruit in a magnetic field accelerates the characteristic changes in acids and sugars. PM increases the firmness of the fruit, extending its shelf life [91–93,107]. Many studies confirm that the electric field extends the shelf life of the fruit. HVEF slows down the respiration rate, affects the production of ethylene, and slows down the ripening of the fruit. The electric field prolongs the shelf life and freshness of the fruit by inhibiting the activity of enzymes and the inhibition of microbial action [97,102,109,119].

2.5. Effect of Magnetic Fields and Electrical Fields on Fruit Quality

Magnetic and electrical fields affect various plant characteristics and stimulate the growth of the plant. Strengthening the anabolic processes taking place in the plant by applying an electric and magnetic field may lead to an improvement in the quality of the fruit [5,9,15,18,65,106,112,113,120,121]. A summary of the effect of MF and EF on fruit quality is presented in Table 3.

Table 3. Summary of the total effect of magnetic fields and electrical fields on fruit quality.

Variety	Method	MF Parameter	Effect	References
Apple *Gloster* *Jonagold* *Ligol* *Rubin*	Fruit treatment during growth and ripening on the tree	PMF 5–100 mT AMF 50–150 uT and 5–100 mT for 5 min with 6 replicates each for 7 days	Increase in extract content for 100 uT, 8% more fructose and 25% more glucose were produced in the fruits stimulated during ripening	Zaguła, Puchalski 2013 [122]
Cherry fruits (*Prunus avium*)	Fruit treatment	PMF 0–20 mT AMF 0–2 mT During freezing process	Decrease in the phase change, time with PMF consumes less energy, the average ice crystal area achieved a reduction of 67% and 78% with PMF and AMF, respectively	Tang et al., 2021 [123]
Mandarin *Balady* and *Fremont*	Irrigating trees with magnetic water	MF in the range of 3.5–136 mT	Increase in firmness, total soluble solid, vitamin C, fruit weight and yield, but decrease in total acidity	Hamdy et al., 2015 [86]
Melon *Hetao*	Treatment of intact fruit using 2 parallel couples of coils, then cut in pieces and stored	AMF 2 mT for 5, 10, 15, 20 and 25 min	Increase in firmness, soluble solids (after 15 min), decrease in decomposition rate and titratable acid (after 2 days)	Jia et al., 2015 [124]
Strawberries *Elkat, Ventana, Honeyoe*	Fruit treatment during vegetation time on plants	SMF 5–100 mT, AMF 50–150 uT and 5–100 mT for 5 min with 5 replicates each 5 days	Increase in fructose content for 100 uT and with a frequency of 50–100 Hz	Zaguła et al., 2017 [125]
Tomato	Irrigation of trees with magnetic water	MF 12.4, 31.9, 71.9 mT	Increase in heavy metal content (Pb). No differences in vitamin content (A and C)	Yusuf and Ogunlela 2016 [126]
Apples *Fuji* and *Golden Delicious*	Fruit treatment with needle and plate electrode (CD) or 2 parallel plates (PP), reversed EF and forward EF	EF +/−1.25 kV/cm within storage	Using (CD), increase in weight loss, soluble sugar concentration, respiration and decrease in degree of change of hue. Using (PP), decrease in weight loss, soluble sugar concentration and respiration	Atungulu et al., 2003 [96]

Table 3. *Cont.*

Variety	Method	MF Parameter	Effect	References
Mango fruits *Irwin*	Fruit treatment with titanium plate and needle	EF 1.5 kV/cm of electric field for 45 min before storage	Decrease in antioxidative capacity of ripe fruit, no changes in ascorbic acid, carotene, quercetin, total phenols soluble solids, titratable acidity, firmness	Shivashankara et al., 2004 [119]
Persimmon fruits (*Diospyros kaki*)	Fruit treatment between two plates	EF field of 6 kV/cm for 30, 60, 90 or 120 min, 6 duplicates, before storage	Decrease in malondialdehyde content and pectinesterase activity, no change in total phenols (but some increase in MDA after treatment)	Liu et al. 2017 [101]
Persimmon fruits (*Diospyros kaki*)	Fruit treatment between the two plates	EF 7 kV/cm for 3, 6, 9 days within storage	Increase in total content of phenolic compounds, antioxidant activity and firmness	Jaisue et al., 2020 [127]
Seagrape (*Coccoloba uvifera*)	Fruit treatment with two-tier-parallel board before 9 days storage	EF 7.5 kV/cm for 60 min	Decrease in water loss, malondialdehyde (MDA), increase in total phenolic content (TPC), total chlorophyll content	Sulaimana et al., 2021 [128]
Strawberries *Selva*	Fruit treatment using a pin-to-plate	EF intensity of 3.61, 4.56, and 5.13 kV/cm for 60 min	Decrease in loss of mass of fruit, without changes in soluble solid content, pH, titratable acidity, softness and colour but preventing *Botrytis cinerea* growth	Esehaghbeygi et al., 2021 [105]
Tomato *Chaoyan-219*	Fruit treatment with 2 stainless steel plates	EF +/−2 kV/cm For 2 h	Growth in content of GSH, ascorbic acid as well as polyphenols. The activity of enzymes of SOD, APX and CAT was meaningfully higher than that of the control while storage	Zhao et al., 2011 [103]
Tomato *Pannovy*	Fruit treatment at harvest with steel plates as electrodes	Direct electric current 100, 300, 500 mA for 15, 30, 60 min	Increase in content of lycopene, B-carotene, total phenol content and antioxidant activity	Dannehl et al., 2011 [129]

Researchers irrigated the plants with magnetic water to enhance the quality of the fruit. Hamdy et al. (2015) indicated an increase in the total soluble solids of mandarin fruits when irrigation aqua was subject to a magnetic field in comparison with the control [86]. This may be due to increasing ion mobility and ion uptake and in the activities of antioxidant enzymes. They also stated that, in comparison with the control, there is an increase in fruit firmness of one variety and of the vitamin C content of fruits expressed as ascorbic acid/100 mL of fruit in both varieties when treated with magnetic water [86]. This same trend in comparison with that of the control was found by Yusuf and Ogunlela (2016) for the content of vitamins A and C when magnetic water was used for the irrigation of tomatoes. The highest values of these parameters were recorded at magnetic field values of 124 G and 719 G, respectively [126]. The treatment of whole fruit with a field improved their structural properties. The study of Zaguła et al. (2010) also showed an increase in firmness of strawberry fruits of up to 30% using an AMF of 50–150 uT in comparison with the control [94]. MFs penetrate deeper into cells and tissues; therefore, they can influence metabolic pathways at the cellular level [130]. On the other hand, Bourget et al. (2012) stated that a magnetic field, at low doses of 2.5 mT, did not influence the firmness of tomato fruit during storage at 16 °C [93]. However, treatment with AMF at 2.5 mT before the cutting of melo fruits influenced firmness, which was 54.9% higher in comparison with the control. These results showed that AMF retarded the softening of fruit tissue [124].

Other studies showed that the selected magnetic field of 100 µT at 50 Hz that was applied significantly influenced the quality parameters of fruits. Apple fruits treated with an MF had 8 and 25% more fructose and glucose, respectively, when compared to the control. There was also a general tendency to improve the content of the total extract of strawberries from 6–9% depending on variety [122,125,131]. A similar tendency was noted by Boe et al. (1968), who showed that tomato fruits treated with an MF of 6 mT had higher concentrations of glucose, beta carotene, and lycopene relative to control fruit [92]. However, Tang et al. (2020) used magnetic field pre-treatment of 10 mT for PMF and 1.26 mT for AMF to improve the quality of frozen cherry fruit. The application of a magnetic field could reduce drip loss to some extent. Ice crystals formed homogeneously in the cells when a magnetic field was applied. Compared to the control group, this achieved a reduction in the average area of ice crystals of 67% and 78% with a PMF and AMF, respectively [123].

Many studies have proved that an electric field may also affect the quality of fruits. The mass loss at the end of storage for those samples treated with a HVEF at 4.56 kV·cm^{-1} was 1.36%, while it was 3.98% for the control [105]. Another study revealed the effect of ACEF in reducing water loss after nine days of storage of sea grapes [128]. Wang et al. (2008) showed that firmness in tomato fruit treated with a −2 kV/cm electric field was 102.9% higher than that of control fruit on day 20 of storage [102]. The same results were obtained by Jaisue et al. (2020) with an electric field (7 kV/cm), showing that, after 15 d of storage, firmness of treated persimmons was higher than the control [127]. Other researchers pointed out that the application of HVEF can effectively reduce deterioration of apple colour postharvest and weight loss during storage [96,97,102,131].

Use of high-voltage electrical field treatment may also maintain the content of ascorbic acid, carotene, antioxidant capacity, taste, fruit colour, and a high level of soluble solids in mango fruits (*Mangifera indica*) for up to 20 days in storage at 5 °C when compared with a control [119]. Zhao et al. (2011) also showed that the content of non-enzyme antioxidants, such as GSH, ascorbic acid, and polyphenols, and the activities of antioxidant enzymes containing catalase, superoxide dismutase, ascorbate peroxidase, as well as peroxidase, in −2 kV/cm HVEF-treated tomato fruit were pointedly higher before those in the control during storage at 13 °C [103]. Dannehl et al. (2011) confirmed that direct current (DC 500 mA for 15 min) treatment of harvested tomatoes affected the secondary metabolism of fruits, which showed a high content of total phenol, lycopene, ß-carotene, and antioxidant activity [129]. However, Wang et al. (2008) indicated that the lycopene content in tomato fruit treated with an electrical field was invariably lower before that in control fruit amid the entire storage period [102]. The study of Liu et al. (2017) also showed the benefits of the application of an electrical field in maintaining the physicochemical properties of persimmon fruits. However, they are different according to structure, physiological metabolism, and electric properties from other products [101]. Persimmons treated with 600 kV/m for different lengths of time (0, 30, 60, 90, or 120 min) in samples stored at 25 °C showed almost 2.5-fold lower pectinesterase (PE) activity after 12 days of storage in comparison with the control [101]. These changes involved the action of cell wall hydrolysis enzymes, such as pectinesterase (PE) and polygalacturonase (PG) [132,133]. Pectin degradation plays an important role in the ripening of fruit via the disassembly of cellulose that contributes to fruit firmness. Hsieh et al. (2020) explained the effect of phenolic content on cell membrane integrity [134].

Sulaimana et al. (2021) reported that alternating current electric field (ACEF) with 125 kV/m of intensity for 60 min reduced malondialdehyde (MDA) production and chlorophyll degradation and increased total phenolic content (TPC) of sea grapes during nine days of storage in comparison with the control [128]. The observation by Han and Fumio (1997) that alternant high-voltage electric field treatment could hold up the comedown of chlorophyll and flavonoids in mandarin fruit was confirmed [115]. Delaying the degradation of chlorophyll and malondialdehyde (MDA) production under the effect of an electrical field was also demonstrated by Wang et al. (2008) and Liu et al. (2017) by comparison with the control [101,102]. Jaisue et al. (2020) showed increased total phenolic content and enhanced antioxidant activity in persimmon fruits by application of electric field treatment and comparison with a control [127]. This is consistent with the results obtained by Jeya et al. (2018) for grape extract and Rodríguez-Roque et al. (2015) for blueberry, showing the response of plants to induced stress and the inactivation of the enzymes involved in phenolic compound oxidation by an electric field [135–137]. Jiang et al. (2010) stated that the presence of phenolic compounds helps to contribute to the sensory attributes (taste, colour, texture, and aroma) [138]. The mechanism of HVEF is to interfere with the fruit's physiological biochemical metabolism by a high-voltage electrostatic field and, thus, affect the molecules' interaction and dynamics in cells. From the study of Wagner et al. (2006) it might be assumed that the electrical field increases cell membrane permeability by influencing the voltage-gated ion channels [139]. In addition, calcium-dependent protein kinases (CDPKs or CPKs) induced by stress are involved in stress signalling, hormone response, and regulation of a given metabolic pathway [140–142]. Consequently, it may result in an increase in freshness in fruit and vegetables [143]. On the other hand, a high-voltage electrical field of −35 kV/cm leads to irreversible damage to the cell membrane, resulting in an increase in the lycopene and ß-carotene content [144].

The literature reports numerous benefits of using magnetic and electric fields on fruit quality [5,145,146]. The treatment with an electric or magnetic field improves the structural properties of the fruit and inhibits the loss of water in the tissues. Magnetic and electric fields significantly delay the softening of the fruit tissue and increase the firmness of the fruit. Treatment with an electric or magnetic field significantly affects the quality parameters of the fruit and increases the concentration of glucose, beta carotene, lycopene, and vitamins A and C. The use of MF and EF has a positive effect on the content of phenolic compounds and antioxidant enzymes [5,108]. Effects of magnetic and electric field on the morphophysiological properties of fruits, with possible mechanism of action, are represented in Figure 2.

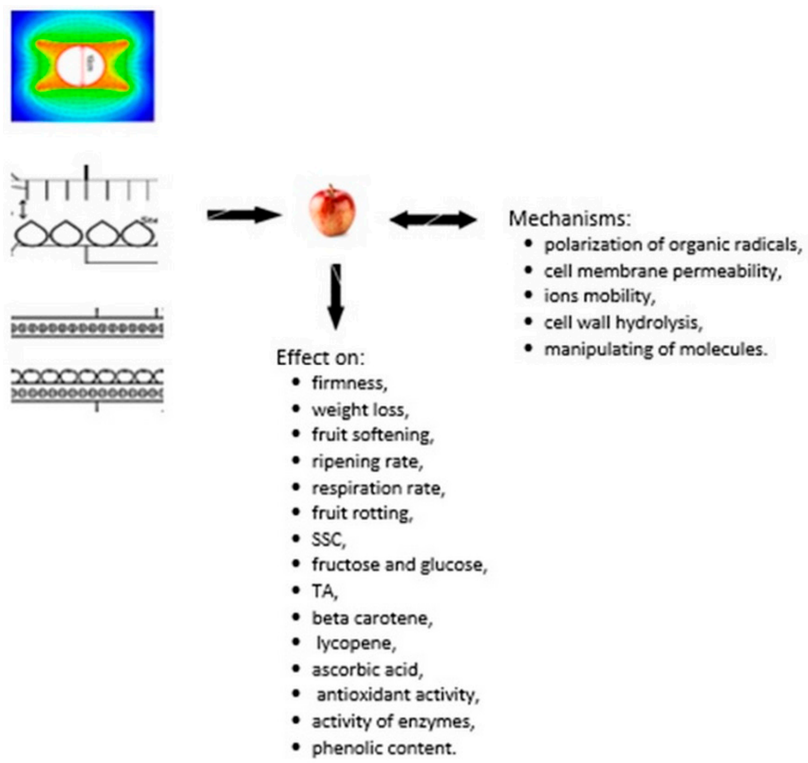

Figure 2. Magnetic and electric field affecting the morphophysiological properties of fruit, with possible mechanisms.

3. Conclusions

The objective of this paper was to review scientific results and summarise the emerging field of the effects of magnetic and electrical fields on the growth, yield, ripening, and shelf life of fruits and fruit quality, as well as the potential application of MF and EF in agricultural production. The results varied depending on the plant system, namely on the pre-treatment of seedlings, seed germination, plant growth, development and ripening, and the different categories of magnetic and electrical field intensity and exposure time applied to plants [49,105,145,147].

Alternating magnetic fields (AMF) with a value of 0.1–200 mT were the most commonly used with 50 Hz or 60 Hz power frequency for the treatment of seedlings, plants, fruits, and irrigated water. This magnetic field mainly caused the following effects on plant growth regardless of the treatment method: increase in speed of germination, plant height, shoot and root weight, and dry weight of the plant. It has contributed to improving fruit growth parameters, number of plant leaves, leaf area, number of flowers/plant, number of fruits/plant, fruit yield, average fruit weight, and the N, K, Ca, Mg, Fe, Mn, and Zn in foliage. These matters also influenced the shelf life of the fruit and its quality, mainly through an increase in firmness, ripening rate, beta carotene and lycopene, sugar concentration, fructose content, and a decrease in acidity and respiration rate.

High-voltage electrical fields (HVEF) with values of 2–3.61 kV/cm were the most commonly used treatments of fruits. Electrical fields were used to extend the shelf life and improve the quality of the fruit mainly through: a decrease in respiration rate and ethylene generation, and extension of post-harvest life. This is also related to delaying the decline in firmness, as well as the transformation in colour, entire soluble sugar, and also titratable acidity of fruit and an increase in the content of reduced glutathione, ascorbic acid, and polyphenols. The action of enzymes of SOD, APX, and CAT was suggestively higher than that of the control when in storage.

The use of electric and magnetic fields is a potential method to increase crops, improve crop quality, prevent disease and pest damage, and inhibit fruit aging. Exposing plants and fruits to an electric and magnetic field is an economic, safe, and environmentally friendly method. Despite numerous attempts, there are still difficulties in applying magnetic and electric fields in field and greenhouse conditions. Further experimentation is needed to develop magnetic- and electric-field-generating devices suitable for use in field and greenhouse crops. Moreover, the inconsistencies of the research results suggest that the effects of magnetic and electric fields on plants and fruit are species-specific and depend on the field strength and exposure time. This has promising research potential for the coming years. The application of electric and magnetic fields in field and greenhouse conditions also causes difficulties. This is another topic for further research.

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Abbreviations

AMF	alternating magnetic fields
MF	magnetic fields
EF	electrical fields
HVEF	high voltage electrical field
PE	pectinase
MFD	magnetic flux density
SOD	superoxide dismutase
APX	ascorbate peroxidase
CAT	catalase
LFMF	low frequency magnetic field
SLA	specific leaf area
N	nitrogen
K	potassium
Ca	calcium
Mg	magnesium
Fe	iron
Mn	manganese
Zn	zinc
P	phosphorus
Na	sodium
Cu	copper
Pb	lead
PP	parallel plate
NdFeb	neodymium magnet
SMF	static magnetic field
NPK	nitrogen phosphorus potassium
SPMF	Sequentially programmed magnetic field
GMF	geomagnetic field
DC	direct current
AC	alternating current
PMF	pulsed magnetic field
MDA	malondialdehyde
TPC	total phenolic content
GSH	glutathione
ACEF	alternating current electric field
PG	polygalacturonase
CDPK	the calcium-dependent protein kinase
CPK	the calcium-dependent protein kinase

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