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# Chemical Constituents, Antimicrobial Activity, and Food Preservative Characteristics of *Aloe vera* Gel

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**Abstract:** Edible coating gels developed from the *Aloe vera* plant have been used as a traditional medicine for about 3000 years. *Aloe vera* contains approximately 110 potentially active constituents from six different classes: chromone and its glycoside derivatives; anthraquinone and its glycoside derivatives; flavonoids; phenylpropanoids and coumarins; phenylpyrone and phenol derivatives; and phytosterols and others. Apart from medicinal uses, *Aloe* gels have an important role in food preservation as edible coatings. They provide an edible barrier for atmospheric gases and moisture and help to reduce the respiration and transpiration of fresh produce, which helps to preserve its postharvest quality. To date, numerous studies have been conducted on the postharvest use of *Aloe vera* gel. The present review article summarizes and discusses existing available information about the chemical constituents, antimicrobial activity, and food preservative characteristics of *Aloe vera.*

**Keywords:** *Aloe vera*; chemical constituents; antimicrobial activity; postharvest storage; biodegradable; edible coating

## 1. Introduction

Food quality mainly refers to three attributes: external (size, color, appearance, etc.), internal (taste, color, juicy, texture, seedless, etc.), and hidden (food safety and nutritional contents). External and internal quality attributes were of greatest importance to consumers for many years. However, since the occurrence of food-derived health problems has begun to increase, consumers have started to pay more attention to the hidden quality attributes of fresh produce and are asking for food to be free of chemical residues [1]. Fungicides and other agrochemicals are of great importance in controlling postharvest diseases and have crucial role for the preservation of the postharvest quality, but misuse and/or excessive use of them might cause negative impacts on human health [2,3]. There is an increasing effort in postharvest studies to develop natural preservatives and antimicrobials to extend the storage duration of foods without chemical preservatives [4,5]. So far, many storage techniques and natural preservatives have been developed to extend the postharvest life of foods. The currently utilized natural preservatives are chitosan [6,7], essential oils [8,9], propolis extract [10], plant extracts [11,12], edible coatings [13,14], and organic salts [15]. Among these, edible coatings have been receiving more attention in recent years due to their potential for developing edible packaging materials [16]. Weight loss, changes in textural quality, changes in chemical structure, and microbial pathogens (mostly fungus) are the most important postharvest problems for foods [17,18].

*Aloe* belongs to the family of Xanthorrhoeaceae, which consists of about 420 species, and has been used as a traditional medicine for about 3000 years [19]. The perennial plant known as *Aloe vera* is *Aloe barbadensis* Miller, which is a well-known pharmaceutical herb that has long been used in traditional Chinese medicine for the treatment of various diseases. It is widely distributed in the semitropical regions and cultivated in many provinces of China.

*Aloe* gels have an important role in food preservation as edible coatings. Edible coatings generally provide a thin layer on the fruit surface, which acts as a barrier to atmospheric gases and moisture [20,21]. *Aloe* gels help to reduce the respiration and transpiration of fresh produce and delay postharvest deterioration of foods, promoting food preservation [17]. Edible coatings are generally applied by dipping the foods, spraying, or brushing. To date, numerous studies have been conducted into the postharvest use of *Aloe vera* gel as an edible coating. The following sections of the present review article aim to summarize and discuss the existing available information regarding the use of *Aloe vera* gel as a food preservative. First, however, it is important to mention the chemical constituents and antimicrobial activity of *Aloe vera*, which are summarized herein.

## 2. Chemical Constituents of *Aloe vera*

The two-main class active constituent of the *Aloe vera* plant extract are chromone and anthraquinone and its glycoside derivatives, alongside others such as phenylpyrone derivatives, flavonoids, phenylpropanoids, coumarins, phytosterols, naphthalene analogs, lipids, and vitamins.

### 2.1. Chromone and its Glycoside Derivatives

Approximately 29 chromone derivatives were isolated and identified from *Aloe vera* (Table 1, Figure 1). Aloesin (1, formerly called aloeresin B), aloeresin A (23), isoaloeresin D (13) and aloeresin E (9) are the most significant active constituents of *Aloe vera*. Three aloediols (7, 8, and 9) were isolated and identified from *Aloe vera*, but the absolute configuration has not yet been determined.

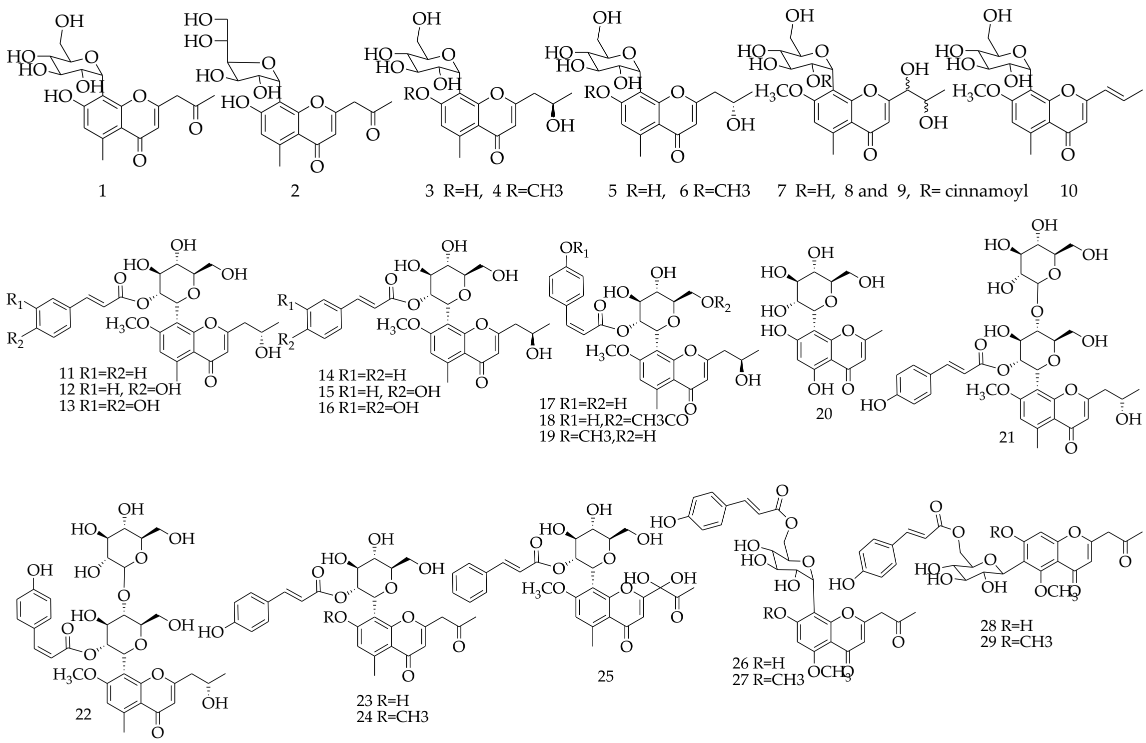


**Figure 1.** Chemical structure of chromone and its glycoside derivatives from *Aloe vera*.

**Table 1.** Chromone and its glycoside derivatives isolated and identified from *Aloe vera*.

| No | Constituents | Molecular Formula | Exact Mass | References |
|---|---|---|---|---|
| 1 | aloesin | $C_{19}H_{22}O_9$ | 394.1264 | [22,23] |
| 2 | neoaloesin A | $C_{19}H_{22}O_9$ | 394.1264 | [24] |
| 3 | 8-*C*-glucosyl-(*R*)-aloesol | $C_{19}H_{24}O_9$ | 396.142 | [22] |
| 4 | 8-*C*-glucosyl-7-methoxy-(*R*)-aloesol | $C_{20}H_{26}O_9$ | 410.1577 | [22] |
| 5 | 8-*C*-glucosyl-(*S*)-aloesol | $C_{19}H_{24O9}$ | 396.142 | [25] |
| 6 | 8-*C*-glucosyl-7-methoxy-(*S*)-aloesol | $C_{20}H_{26}O_9$ | 410.1577 | [25,26] |
| 7 | 8-*C*-glucosyl-7-*O*-methylaloediol | $C_{20}H_{26}O_{10}$ | 426.1526 | [22,25] |
| 8 | 8-glucosyl-(2′-O-cinnamoyl)-7-O-methylaloediol A | $C_{29}H_{32}O_{12}$ | 572.1894 | [27] |
| 9 | 8-glucosyl-(2′-O-cinnamoyl)-7-O-methylaloediol B | $C_{29}H_{32}O_{12}$ | 572.1894 | [27] |
| 10 | *C*-2′-decoumaroyl-aloeresin G | $C_{20}H_{24}O_8$ | 392.1471 | [22] |
| 11 | aloeresin E | $C_{29}H_{32}O_{10}$ | 540.1995 | [26] |
| 12 | isoaloeresin D | $C_{29}H_{32}O_{11}$ | 556.1945 | [26,28,29] |
| 13 | iso-rabaichromone | $C_{29}H_{32}O_{12}$ | 572.1894 | [25] |
| 14 | 8-[*C*-*β*-D-[2-*O*-(*E*)-cinnamoyl] glucopyranosyl]-2-[(*R*)-2-hydroxypropyl]-7-methoxy-5-methylchromone | $C_{29}H_{32}O_{10}$ | 540.1995 | [30] |
| 15 | aloeresin D | $C_{29}H_{32}O_{11}$ | 556.1945 | [22,30] |
| 16 | rabaichromone | $C_{29}H_{32}O_{12}$ | 572.1894 | [22] |
| 17 | allo-aloeresin D | $C_{29}H_{32}O_{11}$ | 556.1945 | [22] |
| 18 | aloeresin K | $C_{31}H_{34}O_{12}$ | 598.205 | [29] |
| 19 | aloeresin J | $C_{30}H_{34}O1_1$ | 570.2101 | [29] |
| 20 | 8-C-glucosyl-noreugenin | $C_{16}H_{18}O_9$ | 354.0951 | [27] |
| 21 | 4′-O-glucosyl-isoaloeresin DI | $C_{35}H_{42}O_{16}$ | 718.2473 | [27] |
| 22 | 4′-O-glucosyl-isoaloeresin DII | $C_{35}H_{42}O1_6$ | 718.2473 | [27] |
| 23 | aloeresin A | $C_{28}H_{28}O_{11}$ | 540.1632 | [23] |
| 24 | 7-O-methyl-aloeresin A | $C_{29}H_{30}O_{11}$ | 554.1788 | [23,31] |
| 25 | 9-dihydroxyl-2′-O-(Z)-cinnamoyl-7-methoxy-aloesin | $C_{29}H_{30}O_{12}$ | 570.1737 | [31] |
| 26 | 6′-*O*-coumaroyl-aloesin | C28H28O12 | 556.1581 | [32] |
| 27 | 7-methoxy-6′-*O*-coumaroyl-aloesin | C29H30O12 | 570.1737 | [33] |
| 28 | aloeveraside B | $C_{28}H_{28}O_{12}$ | 556.1581 | [32,34] |
| 29 | aloeveraside A | $C_{29}H_{30}O_{12}$ | 570.1737 | [32,34] |

### 2.2. Anthraquinone and its Glycoside Derivatives

Approximately 32 anthraquinones and their glycoside derivatives were isolated and identified from *Aloe vera* (Table 2, Figure 2). The isomers of aloin A (30) and aloin B (31), two anthraquinone glucosides, are the most abundant active constituents of *Aloe vera*. However, chrysophanol (52), emodin (53), physcione (54), aloe-emodin (55) are four major anthraquinone aglycones. Six anthraquinone dimmers (45–50) were also identified from *Aloe vera*.

**Table 2.** Anthraquinone and its glycoside derivatives isolated and identified from *Aloe vera*.

| No | Constituents | Molecular Formula | Exact Mass | References |
|---|---|---|---|---|
| 30 | aloin A | $C_{21}H_{22}O_9$ | 418.1264 | [29] |
| 31 | aloin B | $C_{21}H_{22}O_9$ | 418.1264 | [29] |
| 32 | 6′-O-acetyl-aloin A | $C_{23}H_{24}O_{10}$ | 460.1369 | [29] |
| 33 | 6′-O-acetyl-aloin B | $C_{23}H_{24}O_{10}$ | 460.1369 | [29] |
| 34 | 10-hydroxyaloins A | $C_{21}H_{22}O_{10}$ | 434.1213 | [28,32] |
| 35 | 10-hydroxyaloins B | $C_{21}H_{22}O_{10}$ | 434.1213 | [28,32] |
| 36 | aloinoside A | $C_{27}H_{32}O_{13}$ | 564.1843 | [29] |
| 37 | aloinoside B | $C_{27}H_{32}O_{13}$ | 564.1843 | [29] |
| 38 | 7-hydroxyaloin A | $C_{21}H_{22}O_{10}$ | 434.1213 | [23] |
| 39 | 7-hydroxyaloin B | $C_{21}H_{22}O_{10}$ | 434.1213 | [23] |
| 40 | 7-hydroxy-8-O-methylaloin A | $C_{22}H_{24}O_{10}$ | 448.1369 | [23,28] |
| 41 | 7-hydroxy-8-O-methylaloin B | $C_{22}H_{24}O_{10}$ | 448.1369 | [23,28] |
| 42 | 6′-malonylnataloin A | $C_{24}H_{24}O_{12}$ | 504.1268 | [23] |
| 43 | 6′-malonylnataloin B | $C_{24}H_{24}O_{12}$ | 504.1268 | [23] |
| 44 | homonataloside B | $C_{28}H_{34}O_{14}$ | 594.1949 | [23] |
| 45 | elgonica dimer A | $C_{36}H_{30}O_{14}$ | 686.1636 | [29,35,36] |
| 46 | elgonica dimer B | $C_{36}H_{30}O_{14}$ | 686.1636 | [29,35,36] |
| 47 | aloindimer A | $C_{42}H_{42}O_{18}$ | 834.2371 | [29] |
| 48 | aloindimer B | $C_{42}H_{42}O_{18}$ | 834.2371 | [29] |
| 49 | aloindimer C | $C_{42}H_{42}O_{18}$ | 834.2371 | [29] |

**Table 2.** *Cont.*

| No | Constituents | Molecular Formula | Exact Mass | References |
|---|---|---|---|---|
| 50 | aloindimer D | $C_{42}H_{42}O_{18}$ | 834.2371 | [29] |
| 51 | aloe-emodin-11-O-rhamnoside | $C_{21}H_{20}O_9$ | 416.1107 | [32] |
| 52 | chrysophanol | $C_{15}H_{10}O_4$ | 254.0579 | [37] |
| 53 | emodin | $C_{15}H_{10}O_5$ | 270.0528 | [32,37] |
| 54 | physcione | $C_{16}H_{12}O_5$ | 284.0685 | [37] |
| 55 | aloe-emodin | $C_{15}H_{10}O_5$ | 270.0528 | [32,37] |
| 56 | nataloeemodin | $C_{15}H_{10}O_5$ | 270.0528 | [23] |
| 57 | aloesaponarin I | $C_{17}H_{12}O_6$ | 312.0634 | [38] |
| 58 | aloesaponarin II | $C_{15}H_{10}O_4$ | 254.0579 | [38] |
| 59 | madagascine | $C_{20}H_{18}O_5$ | 338.1154 | [39] |
| 60 | 3-Geranyloxyemodin | $C_{24}H_{24}O_5$ | 392.1624 | [39] |
| 61 | rhein | $C_{15}H_8O_6$ | 284.0321 | [37] |

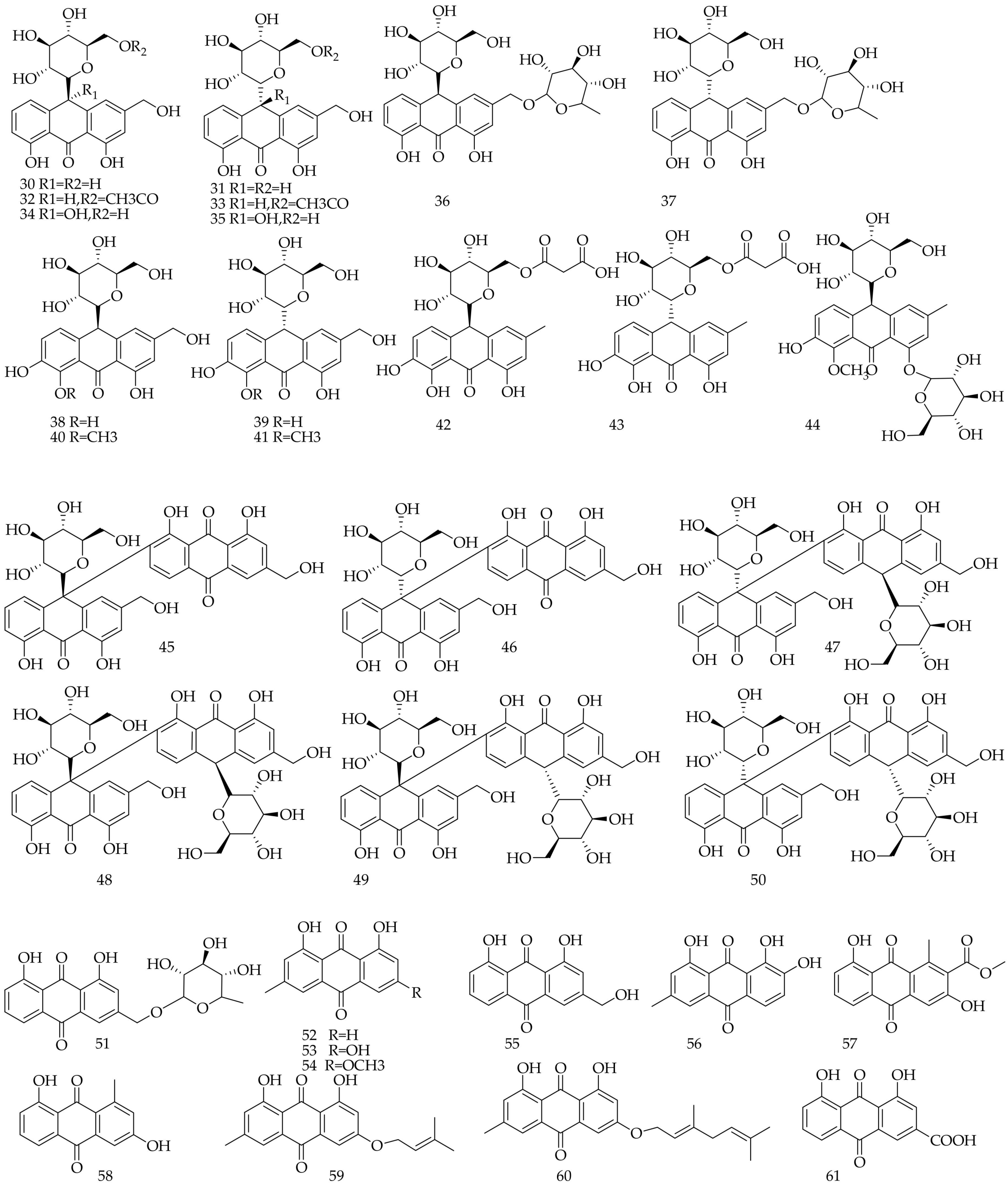


**Figure 2.** Chemical structure of anthraquinone and its glycoside derivatives from *Aloe vera*.

### 2.3. Flavonoids

Approximately 13 flavonoids and their glycoside derivatives were isolated and identified from *Aloe vera* (Table 3, Figure 3), including three types; namely flavone (62–67), flavonol (68–72), and flavan-3-ol (73,74).

**Table 3.** Flavonoids isolated and identified from *Aloe vera.*

| No | Constituents | Molecular Formula | Exact Mass | References |
|---|---|---|---|---|
| 62 | apigenin | $C_{15}H_{10}O_5$ | 270.0528 | [40] |
| 63 | luteolin | $C_{15}H_{10}O_6$ | 286.0477 | [41] |
| 64 | isovitexin | $C_{21}H_{20}O_{10}$ | 432.1056 | [41] |
| 65 | isoorientin | $C_{21}H_{20}O_{11}$ | 448.1006 | [41] |
| 66 | saponarin | $C_{27}H_{30}O_{15}$ | 594.1585 | [41] |
| 67 | lutonarin | $C_{27}H_{30}O_{16}$ | 610.1534 | [41] |
| 68 | kaempferol | $C1_5H_{10}O_6$ | 286.0477 | [40] |
| 69 | quercetin | $C_{15}H_{10}O_7$ | 302.0427 | [40] |
| 70 | myricetin | $C_{15}H_{10}O_8$ | 318.0376 | [40] |
| 71 | quercitrin | $C_{21}H_{20}O_{11}$ | 448.1006 | [40] |
| 72 | rutin | $C_{27}H_{30}O_{16}$ | 610.1534 | [40] |
| 73 | catechin | $C_{15}H_{14}O_6$ | 290.0790 | [40] |
| 74 | epicatechin | $C_{15}H_{14}O_6$ | 290.0790 | [40] |

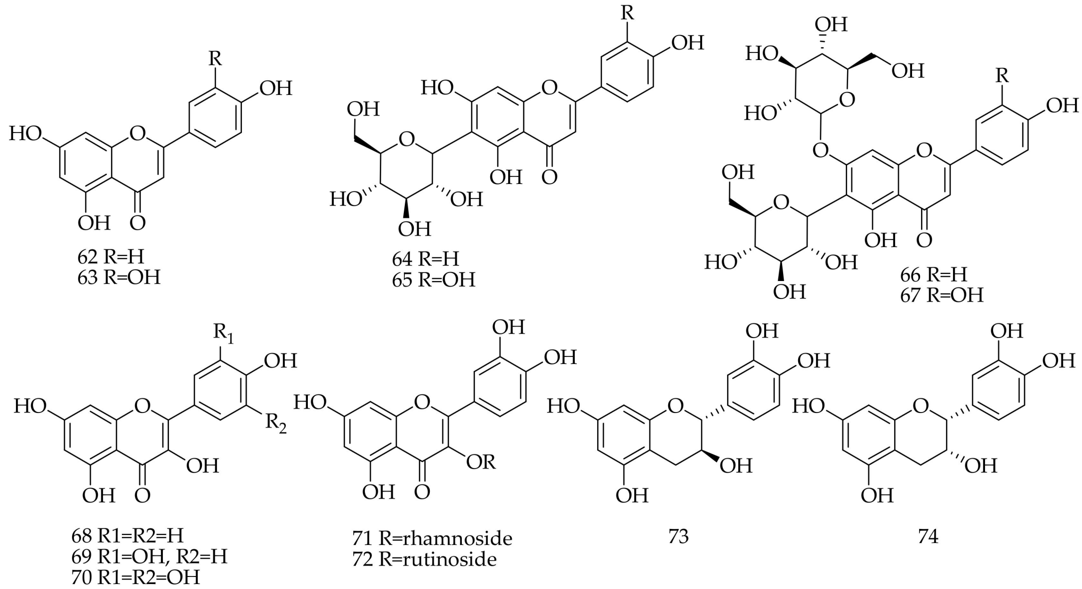


**Figure 3.** Chemical structure of flavonoids from *Aloe vera.*

### 2.4. Phenylpropanoids and Coumarins

Approximately 12 phenylpropanoid acids and their ester derivatives (75–86), and four coumarins (87–90), were isolated and identified from *Aloe vera* (Table 4, Figure 4).

**Table 4.** Phenylpropanoids and coumarins isolated and identified from *Aloe vera.*

| No | Constituents | Molecular Formula | Exact Mass | References |
|---|---|---|---|---|
| 75 | cinnamic acid | $C_9H_8O_2$ | 148.0524 | [42] |
| 76 | p-coumaric | $C_9H_8O_3$ | 164.0473 | [40] |
| 77 | caffeic acid | $C_9H_8O_4$ | 180.0423 | [40] |
| 78 | ferulic acid | $C_{10}H_{10}O_4$ | 194.0579 | [40] |
| 79 | sinapic acid | $C_{11}H_{12}O_5$ | 224.0685 | [40] |
| 80 | 5-p-coumaroylquinic | $C_{16}H_{18}O_8$ | 338.1002 | [41] |

**Table 4.** *Cont.*

| No | Constituents | Molecular Formula | Exact Mass | References |
|---|---|---|---|---|
| 81 | chlorogenic | $C_{16}H_{18}O_9$ | 354.0951 | [40] |
| 82 | 5-feruloylquinic | $C_{17}H_{20}O_9$ | 368.1107 | [41] |
| 83 | caffeoylshikimic | $C_{16}H_{16}O_8$ | 336.0845 | [41] |
| 84 | 5-p-cis-coumaroylquinic | $C_{16}H_{18}O_8$ | 338.1002 | [41] |
| 85 | 3-(4-hydroxyphenyl) propanoic acid | $C_9H_{10}O_3$ | 166.063 | [32] |
| 86 | methyl 3-(4-hydroxyphenyl) propionate | $C_{10}H_{12}O_3$ | 180.0786 | [32] |
| 87 | 7-demethylsiderin | $C_{11}H_{10}O_4$ | 206.0579 | [32] |
| 88 | feralolide | $C_{18}H_{16}O_7$ | 344.0896 | [33,36] |
| 89 | dihydrocoumarin | $C_{22}H_{18}O_7$ | 394.1053 | [43] |
| 90 | dihydrocoumarin ethyl ester | $C_{25}H_{26}O_7$ | 438.1679 | [43] |

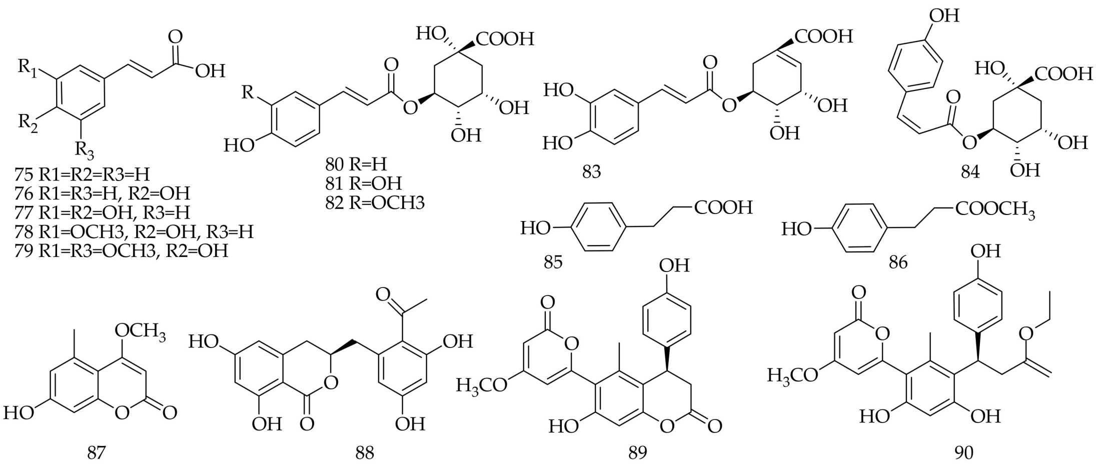


**Figure 4.** Chemical structure of phenylpropanoids and coumarins from *Aloe vera*.

## 2.5. Phenylpyrone and Phenol Derivatives

Approximately three phenylpyrone derivatives (91–93), one triglucosylated naphthalene derivative named aloveroside A (94), and one 1-methyltetralin derivative feroxidin (95) were isolated and identified from *Aloe vera* (Table 5, Figure 5). Nine phenol derivatives (96–104) and vitamin C (105) were also isolated from *Aloe vera*.

**Table 5.** Phenylpyrone and phenol derivatives isolated and identified from *Aloe vera*.

| No | Constituents | Molecular Formula | Exact Mass | References |
|---|---|---|---|---|
| 91 | aloenin A | $C_{19}H_{22}O_{10}$ | 410.1213 | [44] |
| 92 | aloenin B | $C_{34}H_{38}O_{17}$ | 718.2109 | [35,44] |
| 93 | p-coumaroyl aloenin | $C_{28}H_{28}O_{12}$ | 556.1581 | [35] |
| 94 | aloveroside A | $C_{30}H_{40}O_{17}$ | 672.2265 | [35] |
| 95 | feroxidin | $C_{11}H_{14}O_3$ | 194.0943 | [32] |
| 96 | 1-(2,4-dihydroxy-6-methylphenyl) ethanone | $C_9H1_0O_3$ | 166.0630 | [32] |
| 97 | *p*-anisaldehyde | $C_8H_8O_2$ | 136.0524 | [32] |
| 98 | salicylaldehyde | $C_7H_6O_2$ | 122.0368 | [32] |
| 99 | *p*-cresol | $C_7H_8O$ | 108.0575 | [32] |
| 100 | pyrocatechol | $C_6H_6O_2$ | 110.0368 | [42] |
| 101 | gentisic acid | $C_7H_6O_4$ | 154.0266 | [40] |
| 102 | gallic acid | $C_7H_6O_5$ | 170.0215 | [40] |
| 103 | vanillic acid | $C_8H_8O_4$ | 168.0423 | [40] |
| 104 | syringic acid | $C_9H_{10}O_5$ | 198.0528 | [40] |
| 105 | ascorbic acid | $C_6H_8O_6$ | 176.0321 | [40] |

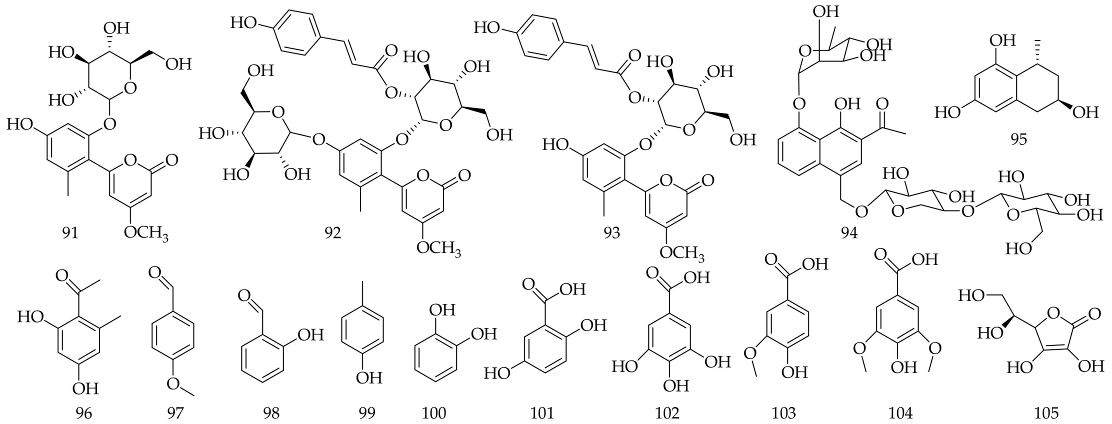

**Figure 5.** Chemical structure of phenylpyrone and phenol derivatives from *Aloe vera.*

### 2.6. Phytosterols and Others

Five phytosterols (Table 6, Figure 6) were isolated from *Aloe vera* gel, including cycloartanol (106), 24-methylene-cycloartanol (107), lophenol (108), 24-methyl-lophenol (109), and 24-ethyl-lophenol (110) [45]. Some polar and nonpolar lipids, as well as prostanoids, were also isolated from *Aloe vera* leaves [46]. Chemical investigation of the major constituents in *Aloe vera* leaves revealed moisture, ash, fiber, protein, lipids, minerals, organic acids, free sugars, and polysaccharides. Glucose, fructose, and'sucrose were the main free sugars. Oxalic, L-Malic, isocitric, lactic, acetic, isocitric, lactone, citric, and fumaric acid were the main organic acids.

**Table 6.** Phytosterols isolated and identified from *Aloe vera.*

| No | Constituents | Molecular Formula | Exact Mass | References |
|---|---|---|---|---|
| 106 | cycloartanol | $C_{30}H_{52}O$ | 428.4018 | [45] |
| *107* | 24-methylene-cycloartanol | $C_{31}H_{52}O$ | 440.4018 | [45] |
| 108 | lophenol | $C_{28}H_{48}O$ | 400.3705 | [45] |
| 109 | 24-methyl-lophenol | $C_{29}H_{50}O$ | 414.3862 | [45] |
| 110 | 24-ethyl-lophenol | $C_{30}H_{52}O$ | 428.4018 | [45] |

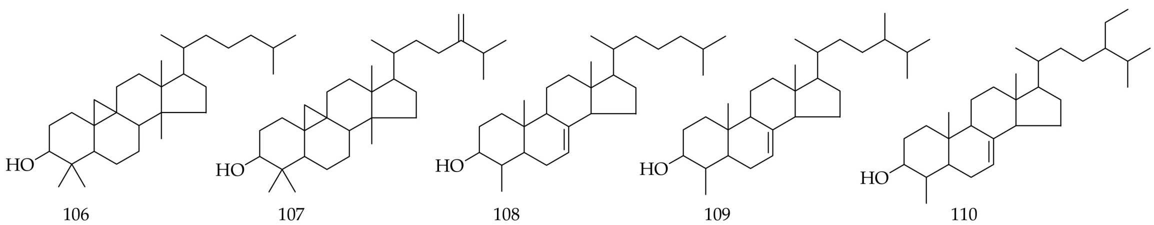

**Figure 6.** Chemical structure of phytosterols from *Aloe vera.*

## 3. Antimicrobial Activity of *Aloe vera*

*Aloe vera* plant extracts have antimicrobial characteristics that kill microorganisms (including bacteria (antibacterial activity), fungi (antifungal activity), and viruses (antiviral activity)) or stop their growth. Fruit decay is an important parameter influencing the postharvest quality of fresh produce. Previous studies have shown that the use of *Aloe vera* gel as an edible coating has positive effects on the prevention of fruit decay and microbial spoilage. The inhibitory effects of *Aloe vera* gel on the growth of mycelium (*Penicillium digitatum* and *Aspergillus niger*) was reported by Nabigol and Asghari [47], who performed a range of laboratory tests. They suggested that the inhibition of the mycelium growth rate increased with gel concentration. The 500 mL/L dose of *Aloe vera* gel was found to cause 100% inhibition of *P. digitatum* and 64% of *A. niger*. According to the findings of Kator et al. [48], 20%, 60%, and 100% concentrations of *Aloe vera* gel are effective in preventing the occurrence of decay in tomato fruits for seven days of storage. However, these authors suggested that a 100% concentration has significantly higher effects, and the positive impact may continue for 16 days of storage. Benitez et al. [49] reported that *Aloe vera* gel provides higher efficacy for the prevention of mesophilic bacteria and yeasts and molds than alginate and chitosan for kiwifruit slices. In another study, the shelf life of guava was reported to be increased by about one more week with the application of an *Aloe vera* gel coating, due to the fact that the edible coating prevents microbial growth [50]. Sitara et al. [51] conducted a comprehensive study regarding the antifungal activity of *Aloe vera* gel at three different doses against five plant pathogenic fungi: *A. niger*, *Aspergillus flavus*, *Alternaria alternata*, *Drechslera hawaiensis*, and *P. digitatum*. The highest test dose (0.35%) of *Aloe vera* gel was reported to completely inhibit the growth of *Drechslera hawaiensis* and *Alternaria alternata*. In another study, the minimum fungicidal concentrations of *Aloe vera* against *Botrytis gladiolorum*, *Fusarium oxysporum* f.sp. *gladioli*, *Heterosporium pruneti*, and *Penicillium gladioli* were reported to vary between 80 and 100 μL/mL, depending on the fungal species [52].

Previous studies have also shown that the combination of *Aloe vera* gel with some homogenizers, such as glycerol starch (0.15 g), improves the efficacy in controlling fungal decay and weight loss in cherry tomatoes [53]. The specific mechanism of action is still unknown, but it is known that saponins, acemannan and anthraquinone derivatives, which are found in *Aloe vera*, have antibacterial activity [54]. Navarro et al. [55] performed a study with *Aloe vera* gel alone or in combination with thymol on nectarines and reported that the *Aloe vera* gel alone is more efficient in prevention of the decay caused by *Rhizopus stolonifer*, *B. cinerea*, and *P. digitatum*. *Aloe vera* gel coatings were previously tested against decay and found to significantly lower counts for molds, yeast, and mesophilic aerobics in different fruits and vegetables, including tomatoes [56,57], citrus fruits [58,59], raspberry fruits [60], blueberries [61], strawberries [62], and ready-to-eat pomegranate arils [63]. The preharvest application of *Aloe vera* gel treatment was also previously tested and found to be effective in postharvest storage; specifically, it was found to reduce the decay incidence of table grapes [64,65].

In a different study [66], *Aloe vera* leaf gel was found to inhibit the growth of two bacteria: *Shigella flexneri* and *Streptococcus progenes*. The antibacterial activities of *A. vera* gel was also reported by Wang et al. [67] and Cellini et al. [68] against *Heliobacter pylori*. Moreover, antiviral activities of *A. vera* have also been of interest to many researchers, wherein its positive influence has been reported against herpes simplex virus (HSV) type 2 strains by Zandi and Rastian [69] and against influenza A virus replication by Li et al. [70].

## 4. Food Preservative Characteristics of *Aloe vera*

Numerous previous studies and the current extensive review have concluded that *Aloe vera* gel coatings have been used to preserve the postharvest quality of numerous fruits (Table 7). Herein, we summarize the effect of *Aloe vera* gel coatings on the external food quality attributes (weight loss, overall appearance, color, and firmness), internal food quality attributes (soluble solids concentration (SSC) and titratable acidity (TA)), and hidden food quality attributes (respiration rate, ethylene production, aroma volatile biosynthesis, and ascorbic acid content) of preserved postharvest fruits.

### *4.1. Effects on External Food Quality Attributes*

*Aloe vera* gel coatings have significant influence on the weight loss (directly related with fruit size), overall appearance, color, and fruit firmness. Among these, weight loss is the most important characteristic and is directly related with a hidden attribute, the respiration rate. Weight loss is mainly a result of respiration (loss of carbon reserves) and transpiration (loss of water). The gel of *Aloe vera* acts as a barrier, thereby restricting water transfer and preventing weight loss. Another study by Achipiz et al. [71] showed that the *Aloe vera*-based edible coating is successful for extending the shelf life of guava (*Psidium guajava*). The researchers suggested that the positive effect of *Aloe vera* in preventing weight loss is the result of the reducing effect of the gel on the respiratory rate of the fruit. The positive effects of *Aloe vera* gel as an edible coating on the prevention of weight loss in pineapple fruits stored at ambient temperatures (27 + 2 °C) and 55–60% relative humidity was also discovered by Adetunji et al. [72]. The researchers reported that coating pineapple fruits with *Aloe vera* gel extends the storability of the fruits by seven weeks. Positive effects of *Aloe vera* gel on the prevention of weight loss were also noted for tomatoes. Kator et al. [48] noted that the use of 20%, 60%, and 100% concentrations of *Aloe vera* gel resulted in 58.20, 59.20, and 65.80 g tomatoes after 16 days of storage, while the untreated tomato fruits were found to have only 25.90 g of fruit. The initial weights of the tested tomato fruits were between 82.40 and 83.80 g for all treatments. In another study [57] it was reported that the different concentrations of *Aloe vera* show different efficacies in the postharvest quality of fresh tomato fruits, and a 15% concentration provides higher efficacy than 5% and 10% concentrations. The positive influence of *Aloe vera* gel on the prevention of weight loss for pomegranate arils was reported by Nabigol and Asghari [47]. It was found that the combination of *Aloe vera* gel with calcium or citric acid improves the efficacy in the prevention of weight loss of grape fruits [65,73]. The positive influence of *Aloe vera* gel on the reduction of the respiration rate was previously reported for kiwifruit slices. The potential postharvest effects of *Aloe vera* gel were also tested under ambient conditions. In one such study, it was found that an *Aloe vera* gel coating prevents weight loss in papaya fruits under ambient conditions [74]. It was also reported that the *Aloe vera* gel coating retards the ethylene production rate, and delays ripening. The impact of *Aloe vera* gel on the postharvest quality attributes is also reported to improve with the combination of some other materials, including chitosan [75], plantain flour [76,77], glycerol starch [53], gum tragacanth [78], rosehip oil [79], and gelatin [80]. Previous studies have also shown that *Aloe vera* gel prevents weight loss in pistachios [81], strawberries [62,82], tomatoes [56,57,83], bell peppers [78], raspberry fruits [60], mangoes [84], blueberries [61], peaches [85], nectarines [86], sour cherries [87], sweet cherries [88], plums [79], fresh-cut papaya fruits [74], fresh-cut oranges [80], and fresh-cut apples [89].

Although food safety and nutrition are of great importance for consumers, visual appearance is still the first impression and a key characteristic in the choice of fruits. Moreover, external color is one of the most important visual characteristics for fruits. Vanaei et al. [81] noted that the application of *Aloe vera* gel protects the brightness of pistachio fruits, and this positive influence increases when the gel is incorporated with chitosan. The researchers noted that the bright color of pistachio bark darkened during storage with all treatments, but the degree of darkening was lowest in the fruits treated with the combination of *Aloe vera* gel (50%) and chitosan (1%). Similarly, a delay in changes in the external color of peach and plum fruits was reported when treatments with *Aloe vera* was undertaken, whereby the chroma index significantly decreased in untreated fruits but the decrease was lower in treated fruits [90]. Similar results were also noted by Benitez et al. [49], who reported that *Aloe vera* gel treated kiwifruit slices have a higher chroma index as compared to untreated fruits. Sharmin et al. [74] conducted a study of papaya fruits and reported that the fruit peel color changed from green to greenish yellow in untreated control fruits; *Aloe vera* treated papayas showed retarded color and physiological changes for up to 12 days during storage. Studies with fresh-cut apples also showed that an *Aloe vera* gel coating 75% (v/v) alleviates browning and helps to maintain surface color [91]. *Aloe vera* gel alone or in combination with gum tragacanth has been reported to delay color changes in bell peppers during long-term storage [78]. Prevention of color changes by the application of an *Aloe vera* gel coating was also reported for mangoes [84], fresh-cut oranges [80], strawberries [62], plums [79], and fresh-cut apples [89].

**Table 7.** Use of *Aloe vera* gel as an edible coating on different fruits.

| Fruits | *A. vera* gel Dose | Compounds Added to *A. vera* gel | Fruit Storage Conditions | Acceptable Storage Duration for | | Ref. |
|---|---|---|---|---|---|---|
| | | | | Untreated Fruits | Treated Fruits | |
| Pineapples | 100% | Ascorbic acid (1.9–2.0 g $L^{-1}$) and citric acid (4.5–4.6 g $L^{-1}$) | Ambient temperature (27 + 2 °C) and 50–60% RH | 21 days | 49 days | [73] |
| Pistachio | 50% and 100% | Chitosan (0.5% and 1.0%) | At 4 °C | - | 30 days | [82] |
| Nectarine cv 'Arctic Snow' | 2.5 g/L | 0.05% Tween-20 | At 0 ± 0.5 °C and 90% ± 5% RH | 21 days | 42 days | [71] |
| Tomato cv. 'Ruchi 618' | 2% | 0.3% antioxidant rich herb, Glycerol (2 %) and oleic acid (0.6%) | N/A | 20 days | 39 days | [84] |
| Tomato cv. 'Dafni' | 10% and 10% | - | At 11 °C and 90% RH in darkness | 7 days | 14 days | [57] |
| Tomato var. 'Roma' and 'UTC' | 20%, 60%, 100% | - | N/A | 7 days | 13–16 days | [48] |
| Table grape 'Crimson Seedless' | 33.3% | - | At 2 °C in controlled chambers with 85–90% RH | 5–10 days | 15–20 days | [64] |
| Grape 'Thompson' | 5% and 10% | - | In air-tight plastic container and at 15 °C, 96–98% RH | 15 days | 40 days | [65] |
| Raspberry (grown naturally in Iran) | 25%, 50%, 75% | - | At 4 °C | 4 days | 8 days | [80] |
| Peach (from Iran) | 25% | - | Air dried and stored at 1 °C and 95% RH | 10 days | 20-30 days | [86] |
| Nectarine cv. 'Flavela' and 'Flanoba' | | 1 mL/L Thymol (99.5% purity) | At 25 °C and 85% RH | - | 6 days | [55] |
| Sweet cherry cv. 'Star King' | 25% | - | Air-dried and stored at 1 °C and 95% RH | 2–6 days | 9–16 days | [88] |
| Plum cv. 'President' | 100% | Rosehip oil (2%) | In a controlled chamber at 20 °C and 85% RH or at 2 °C and 90% RH | 14 days | 28 days | [80] |
| Bell pepper cv. 'Cardio' | 30% | Gum tragacanth (20% w/w) | At 4, 10, 15 and 23 °C | 6 days | 18–22 days | [79] |
| Strawberry cv. 'Bari' | 100% | 1% (w/v) CMC | At 6 ± 1 °C and 50% ± 5% RH | 3–6 days | 12–15 days | [62] |
| Mango var. 'Ngowe' | 25%, 50%, 75% | - | At 13 and 15–22 °C | | | [85] |
| Fresh-cut kiwifruit cv. 'Hayward' | 5% | - | At 4 ± 1 °C and 75% RH | 6 days | 11 days | [49] |
| Fresh-cut papaya cv. Pusa delicious | 100% | 1.5% glycerol | At 4 ± 1 °C and 95% RH | 6 days | 12 days | [75] |
| Ready-to-eat pomegranate arils cv. Mollar de Elche | 50% and 100% | Ascorbic acid and citric acid (0.5% and 1.0%) | At 3 °C and 90% RH | 4 days | 8–12 days | [63] |
| Minimally processed pomegranate arils cv. 'Malas Saveh' | 60, 125, 250, 500 mL/L | - | At 5 °C and 95% RH | - | - | [47] |
| Fresh-cut oranges | 50% and 100% | Gelatin | At 4 °C | 9 days | 17 days | [81] |
| Fresh-cut apples cv. 'Hongro' | 50% | 0.5% Cysteine | At 4 °C | 8 days | 16 days | [89] |

Fruit texture and firmness are important characteristics which affect consumer preferences for fresh produce. Previous studies have shown that the application of *Aloe vera* gel as an edible coating during postharvest storage helps to maintain fruit firmness, or reduce the speed of firmness loss. For example, previous studies have shown that the fruit firmness of pineapples stored at ambient temperatures (27 +2 °C) and 55–60% relative humidity for seven weeks with an *Aloe vera* gel coating was about 600 N, while the firmness of uncoated fruits was found to be less than 100 N at the same time [72]. *Aloe vera* gel at a concentration of 20%, 60%, and 100% was reported to maintain the fruit firmness of tomatoes for about 16 days of storage [48]. Castillo et al. [64] noted similar results for table grapes, while *Aloe vera* gel was found to keep berry firmness higher than the control. Hazrati et al. [85] conducted a study with Aloe vera gel coatings on peach fruits and noted that they protect against enzymes which have cell wall degradation activity. The *Aloe vera* gel coated fruits were reported to maintain the turgorore pressure of the cell walls and incorporate texture enhancers to reduce firmness loss. An *Aloe vera* coating has previously been reported to promote firmness retention in different kinds of fruits and/or ready-to-eat fruits, including pomegranate arils [63], tomatoes [83], peaches [85], strawberries [62], sour cherries [87], sweet cherries [88], plums [79], and fresh-cut apples [89].

### 4.2. *Effects on Internal Food Quality Attributes*

The soluble solids concentration (SSC) and titratable acidity (TA) are among the two most important internal food quality attributes which determines the food flavor. Previous studies showed that *Aloe vera* gel coatings have a significant influence on them. The soluble solids concentration is a measure of the total soluble solids in fruit juices. It plays a crucial role in the taste of fresh produce, and alterations in the SSC are of utmost important for postharvest storage. The SSC content is highly related to the total amount of soluble solids and the water content. Thus, respiration and transpiration have a large influence on the SSC content of fruits. Therefore, *Aloe vera* gel has the potential to prevent the loss of SSC through reducing respiration and transpiration. Nabigol and Asghari [47] reported that different doses of *Aloe vera* gel (60, 125, and 250 mL/L) provide favorable conditions for the storage of pomegranate arils, and help to maintain the SSC for 21 days of storage when compared with untreated pomegranate arils. Similarly, *Aloe vera* gel has been reported to reduce the speed of changes in the soluble solids concentration of strawberries [82], tomatoes [57,83], raspberry fruits [60], blueberries [61], peaches [85], fresh-cut papaya fruits [74], sour cherries [87], sweet cherries [88], and fresh-cut oranges [80].

Researchers reported that the TA of fruits generally decreases during storage, but edible coating materials would provide favorable conditions for reducing the speed of the decrease in TA. It was found that the application of *Aloe vera* gel prevents the loss of acidity in grapefruits, and this effect increases when the *Aloe vera* gel is incorporated with calcium or citric acid [73]. Some other previous studies have also noted that the use of an *Aloe vera* gel coating helps to maintain TA of fruits during storage, including tomatoes [57], raspberry fruits [60], mangoes [84], peaches [85], fresh-cut papaya [74], and fresh-cut oranges [80].

### 4.3. *Effects on Hidden Food Quality Attributes*

Apart from the internal food quality attributes, there are some hidden quality attributes which cannot be understood by consuming the foods but need biochemical analysis to measure. Respiration rate, ethylene production, aroma volatile biosynthesis, and ascorbic acid contents are the most important hidden attributes of fruits and vegetables and are known to be significantly affected by postharvest *Aloe vera* gel coatings. Respiration is an important characteristic for the postharvest quality of fresh produce. The higher the respiration rate during storage, the lower the storage duration of fruits, and vice versa. The gel of *Aloe vera* acts as a barrier, thereby restricting $O_2$ transfer and reducing the respiration rate. Ahmed et al. [86] reported that *Aloe vera* gel reduces the respiration rate, retarding fruit softening and reduce weight loss in 'Arctic Snow' nectarine fruits kept in ambient and cold storage conditions. Researchers used *Aloe vera* gel dried powder (200:1) in a ratio of 2.5/1 (g/L, *w*/*v*) to prepare the coating material, and Tween-20 surfactant was also used at 0.05% concentration. The positive influence of *Aloe vera* gel on the reduction of the respiration rate was previously reported for kiwifruit slices. Benitez et al. [49] noted that the $O_2$ concentration in the headspace of packages decreases in control fruits, but stays higher in fruits treated with *Aloe vera* gel. Contrary to $O_2$, the $CO_2$ level is reported to be lower in the treated fruits. The reason for this influence was attributed to the permeability properties of *Aloe vera* gel by the researchers. Similar findings were reported by Martínez-Romero et al. [63] for ready-to-eat pomegranate arils. The researchers noted that the application of *Aloe vera* alone or in combination with citric acid led to lower $CO_2$ and higher $O_2$ concentrations inside the packages.

Ethylene ($C_2H_4$) is a natural phytohormone responsible for regulation of the growth and senescence of plants [92–94]. It governs the development of leaves, flowers, and especially fruits. Due to its special characteristics, it is used to accelerate the ripening process of climacteric fruits, such as bananas, mangoes, apples, and similar, just before they are transferred to markets. This also allows the harvest of climacteric fruits before ripening and increases the storage duration of the fruits. It was found that the *Aloe vera* gel coating prevents ethylene production by peach and plum fruits, thereby protecting the postharvest quality of the fruits. Guillén et al. [90] reported 70% and 50% inhibition of ethylene production of peach and plum, respectively.

Flavor composition is a complex attribute for fruits, which includes sugars, acids, and volatiles. Aroma has an important influence on consumers' preferences by significantly affecting the four basic flavours (sweetness, sourness, saltiness, and bitterness). Fruit aroma develops from a complex mixture of many volatile compounds, including alcohols, aldehydes, and esters. Storage conditions are known to significantly affect the synthesis, transport, and/or degradation of volatile compounds [95–97]. Although knowledge of the biosynthesis mechanisms of regulation or modulation is still limited, it is known that postharvest practices significantly affect aroma [95]. Previous studies have suggested that *Aloe vera*-based coatings reduce aroma volatile biosynthesis in the fruit pulp of mangoes [13]. The researchers noted that this influence was characterized by the suppression of respiration.

Ascorbic acid (AsA, Vitamin C) is a natural water-soluble vitamin and antioxidant which has the potential to fight bacterial infections, maintain skin, bone, and teeth health, and protect body cells from damage. It is known as an antioxidant and a toxicide. Previous studies have reported that during postharvest storage, ascorbic acid is lost due to the activities of polyphenol oxidase (PPO) [98]. Studies have also suggested that lowering the oxygen content around fresh produce during storage reduces the activities of PPO, and thus the loss of ascorbic acid [99]. *Aloe vera* gel coatings were found to be effective in reducing the loss of ascorbic acid content in pineapple fruits during storage [72]. Wounding of fruits is known to speed up the loss of nutritional properties (i.e., ascorbic acid) of minimally processed fruits by initiating enzymatic browning, which involves the mixing of PPO with phenolic compounds. Ascorbic acid as an antioxidant is mainly involved in oxidative reduction reactions in fresh-cut fruits and is converted to dehydroascorbic acid [100]. An increase in storage duration, high temperatures, low relative humidity, and physical damage have been reported to enhance loss of AsA [101]. Edible coatings of *Aloe vera* gel are reported to prevent the loss of AsA, and retention of AsA in the fruit is important in judging the efficacy of coating materials [74]. The addition of calcium chloride (2%) and citric acid (1%) in *Aloe vera* gel has been reported to retain AsA more effectively in table grapes [73]. Similar positive effects for *Aloe vera* gel were reported for grapefruits [73], strawberries [82], and fresh-cut oranges [80].

## 5. Conclusions: Current Use and Future Trends

Biomaterials derived from plants have a long history of use in human health and as therapeutic agents, and also on the postharvest storage of fresh and processed fruits and vegetables. *Aloe vera* gel coatings are an effective and safe alternative to postharvest chemical treatments. The biological effects and the mechanisms of action responsible for their effects have been extensively studied and reviewed in the last decades; however, the mechanisms remain unclear. Further research into the compounds responsible for antimicrobial activity is of the utmost importance and will broaden the research field of *Aloe vera*. On the other hand, the effects of *Aloe vera* gel coatings on the enzymatic actions, such as catalase (CAT), superoxide dismutase (SOD), peroxidase (POD), and PPO, are highly important for the understanding of the preservative mechanisms [60].

Critical analysis of the existing literature has made it possible to find huge differences among the tested doses and preparation methods of *Aloe vera* gel coatings. These two factors are among the most important factors which determine the success of the preservative materials. The next factor is the product itself, and the selection of the correct dose and suitable preparation method which are highly important for each different product. According to the existing literature, lower doses of *Aloe vera* (≤25%) are effective preservatives for thin-shelled products such as grapes, raspberries, tomatoes, nectarines, and sweet cherries [65,79,83,86,88]; moderate doses (25–50%) are effective for medium-shelled products such as peppers and mangoes [78,84]; and high doses (≥50%) are required for thick-shelled fresh products such as pineapples, plums, and pistachios [72,79,81]. The current literature also shows that the incorporation of *Aloe vera* with ascorbic acid, glycerol, gum tragacanth, rosehip oil, chitosan, oleic acid, and cysteine [63,74,78,79,81,83,89] improves the preservative characteristics of coatings. Incorporation of *Aloe vera* with other edible materials has mainly been tested for minimally processed ready-to-eat fruits and vegetables. Some of these materials were reported to be applied for pH adjustment, and the recommended pH is between 4.0 and 5.6, depending on the characteristics of the fresh produce.

Apart from the dose, additives and pH, pasteurization is very important for stabilization of the gel. The pasteurization temperature is highly important for optimum stabilization and for obtaining good film thickness, water solubility, and swelling behavior. The most used temperature and time interval combinations for pasteurization are 65 °C for 30 min [61]; 70 °C for 45 min [62,65,74,84]; 75 °C for 45 min [50]; 80 °C for 10 s [55]; 80 °C for 10 min [80]; and 90 °C for 30 min [76]. However, some of the previously published articles did not mention pasteurization [82,89]. Among the tested temperature and time interval combinations for pasteurization, the most preferred and successful method was found to be 70 °C for 45 min. However, the effectiveness of the temperature and duration combination for pasteurization has not been adequately explored, and further studies should be carried out on this topic. The dipping duration of the fresh produce into the *Aloe vera* gel is another critical point for improving the efficiency. The literature review showed that there is not a standard dipping time duration for fresh produce, even for the same products in different studies. The most tested dipping durations are 1 min [62,80]; 2 min [87,89]; 5 min [73,74,81,82,85]; 10 min [49,55,88,90]; and 25 min [84]. The "lack of standardization" in the preparation and application methods would not be a problem if they had been tested to compare the effectiveness of the different methodologies. However, the literature search showed no studies for such a comparison. Thus, further studies are needed to determine the optimum dipping time duration.

To conclude, there is not a standard methodology for the preparation and application methods of *Aloe vera* gel, and further studies are required to compare the effectiveness of different methods on the biochemical and physical effectiveness of gel coatings. Based on the existing literature, it is also possible to conclude that the incorporation of *Aloe vera* gel with some other effective biodegradable materials (chitosan, essential oils, propolis, plant extracts, etc.) is important, in order to increase the effectiveness and reduce the application doses of *Aloe vera*.

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