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Silver Nanoparticle Morphology Control via Fruit Juice: A Comprehensive Review

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ABSTRACT

This review explores the influence of fruit juice on the morphology of silver nanoparticles. Fruit juice contains reducing agents that are beneficial for synthesizing nanoparticles, which can impact their shape. The review details the process of synthesizing silver nanoparticles using fruit juice as the reducing agent, along with various characterization techniques employed to analyze their morphology. The findings indicate that fruit juice significantly influences the shape of silver nanoparticles. Factors such as the type of fruit, concentration, mixing time, pH, silver nitrate ratio, and temperature all affect the final size and shape of the nanoparticles. These results suggest that utilizing fruit juice as a reducing agent in nanoparticle synthesis offers a promising strategy for controlling their morphology. This review opens up new possibilities for the application of nanoparticles in healthcare, electronics, and catalysis.

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1. Introduction

Fruit juice consumption has been linked to numerous health benefits due to its rich nutrient content, including vitamins, antioxidants, and minerals [1]. Additionally, nanotechnology (1-100 nm) involves the production, evaluation, and control of components, in particular, the use of silver nanoparticles (AgNPs) has gained significant attention as a promising solution for environmental and biomedical applications [2, 3]. Studies in nanoscience and technology is now heavily focused on green nanomaterials. Colloidal noble-metal nanoparticles have become the focus of much research due to the wide variety of nanomaterials being explored [4, 5]. Research has indicated that fruit juice can effectively control the synthesis of AgNPs by altering their morphology and improving their stability. The influence of fruit juice on AgNPs has been attributed to the presence of various phytochemicals such as ascorbic acid, flavonoids, and tannins that act as reducing and capping agents. Beyond this size, particles are reduced, and the resulting materials exhibit physicochemical properties that are noticeably different from those of their macro-scale counterparts. [6]. Silver nanoparticles are effective because of their tiny size, which enables them to have a large surface area in relation to their volume [7]. Intriguing physicochemical features may be found in nanomaterials, a sector of nanomedicine and bio-nanotechnology that is rapidly developing. Earlier studies found that while a modest quantity of silver is harmful to microbes, it is harmless to human cells. [8, 9]. It is widely recognized that the toxicity of nanomaterials is largely determined by the structure's characteristics, including size, shape, composition, and surface chemistry [10]. It is crucial to choose stabilizing agents and routes that are environmentally benign, non-toxic, and simple to execute if you want to increase the lifespan of metal nanoparticles. In order to achieve the objectives of synthesizing NPs at ambient temperatures, neutral pH, cheap prices, and in an ecologically acceptable manner, nanomaterials have been created utilizing a variety of methods. Phytoextracts are a great way to produce silver nanoparticles and seem to be the most viable option [11-14]. Biosynthesis of nanoparticles is emerging as a viable solution to this issue, with plants as a replacement for chemical and physical methods [15, 16]. The review's goal was to ascertain if fruit juice may affect the shape of silver nanoparticles since doing so would be useful in creating nanomaterials for a variety of uses. The findings of this research might aid in the creation of efficient and affordable processes for the production of controlled-morphology silver nanoparticles.

2. Preparation of silver nanoparticles

The orange juice was used for the preparation of silver nanoparticles, as reported by *Jha et al*, 2011 [17]. The orange juice was diluted and treated with 20 mL of (0.25 M) $AgNO_3$ solution and warmed on the steam bath for 5 minutes until the color of the solution changed to deep reddish-brown and cooled. The strawberry samples were washed with double distilled water to eliminate any adhering particles during the preparation of silver nanoparticles, as reported by Alam 2022 [18]. Subsequently, 10 g of fruit sample was cut into small pieces, boiled with sterile deionized water for 10–15 min, and transferred to an extractor for 5 min. The produced extract spun in a centrifuge at 10000 rpm for 5 min and passed through filter paper. Afterward, the generated filtrate was employed for AgNP synthesis, and the filtrate was kept in a fridge (4°C) for further use. In a regular synthesis protocol, 1 mM $AgNO_3$ was dissolved in 90 mL of sterilized deionized water, and 10 mL of strawberry extract was added simultaneously whilst being stirred continuously at room temperature. Afterward, the strawberry juice was added, the colour alteration was observed. *Zia et al,* 2017 [19] used grape juice as reducing agent for the preparation of silver nanoparticles and its extracts were kept at 4°C until further testing. AgNPs were created by reacting, an aqueous solution of Ag nitrate ($AgNO_3$) with a fruit extract. To reduce the photoactivation of $AgNO_3$, the reaction mixture was kept in the dark at room temperature. The color change initially confirmed the reduction of Ag ion to Ag and the formation silver nanoparticles. The preparation of silver nanoparticles was carried out by using kiwifruit as a reducing agent. They were properly pressed and washed the kiwifruit fruit remove any unwanted impurities and afterword it was centrifuged at 12,000 rpm for 10 minutes and used in subsequent experiments. A 20 mL solution of 0.01% silver acetate was stirred vigorously to reaction temperature and various amounts of kiwifruit juice (0.5 mL, 1 mL, 2 mL, 3 mL, and 4 mL) were added. A color shift from colorless to yellow was observed, indicating the formation of silver nanoparticles, as reported by *Gao et al,* 2014 [20]. The different concentrations of silver nitrate solution were prepared and interacted with Lemon juice in various mixing ratios for varying time periods at 30 ^{0}C in a rotary shaker at 120 rpm until the silver nanoparticles are formed [21]. Silver nanoparticles were prepared by combining an aqueous solution of silver nitrate ($AgNO_3$) with cashew apple juice. To prevent photoactivation of $AgNO_3$, the reaction mixture was kept in the dark at room temperature. The color change indicated the reduction of Ag ions to Ag and the formation of silver nanoparticles [4]. The stability of pear juice should be considered to avoid it from air oxidation and stored in a refrigerator at 20°C in an airtight container. The silver nanoparticles were prepared from a combination of pear juice and silver nitrate solution. The formation of silver nanoparticles is confirmed by appearing yellow-brown color, as reported by Huang et al. 2013 [16]. Gavade et al. 2015 [22] reported the preparation of AgNPs by mixing 5% of carambola juice and $AgNO_3$ stock solution with continuously stirring at 40 °C until the colorless fruit extract solution gradually turned reddish brown, indicating the formation of AgNPs. The synthesis of the variously shaped AgNPs utilized AgNO3 as the precursor compound, cetyltrimethylammonium bromide (CTAB) as the stabilizer, and pomegranate juice as the reducing agent. The varying of constituents and reaction conditions enabled the generation of the distinctively shaped AgNPs [23].

3. Factors effecting on the silver nanoparticles morphology

The concentration of $AgNO_3$, the ratio of silver nitrate to fruit juice, the pH of the solution, the temperature, and the reaction time are just a few of the variables that might affect the synthesis of biosynthesized silver nanoparticles. Its size, form, overall morphology, efficiency, and applicability might be modified by adjusting these variables.

3.1 Concentration of $AgNO_3$

The concentration of silver ions profoundly influences the formation of silver nanoparticles. In order to determine the optimal silver ion concentration for nanostructure fabrication, this variable was studied. Scientists experimented with varying concentrations of *carambola* fruit extract while controlling for other variables (Table 1). They found that the development of larger particles resulted in a broad peak at longer wavelengths, while the formation of smaller particles resulted in a narrow line at shorter wavelengths [24]. Extreme production of AgNPs was achieved by using solutions of varying concentrations of $AgNO_3$. According to the results, 1 mM of AgNO3 results in the highest yield. As the concentration of $AgNO_3$ rose, the yellowish discoloration progressed to a dark brown. The SPR peak became more prominent upon increasing the $AgNO_3$ concentration [25].

3.2 Ratio of silver nitrate

The synthesis of silver nanoparticles is highly sensitive to the volume ratio of silver ion solution to the extract acting as the reducing and stabilizing agent. According to published reports, researchers tracked the effects of varying the $AgNO_3$ /*Carica papaya* fruit juice ratio to achieve maximum output of silver nanoparticles (Table 1). The findings indicated that a 3:1 split was optimal [26]. Ying Gao and colleagues studied the impact of juice quantity on nanoparticle formation. When the extract concentration was raised from 0.5 to 1 mL, the SPR band became more prominent. However, a notable red shift of the SPR band was detected as the juice volume was increased beyond 1 mL. The absorbency improves with increasing amounts of kiwifruit juice. A larger particle size is likely to be responsible for the observed red shift in wavelength [20]. Prathna and his team of researchers [27] tracked the concentrations of silver nitrate in lemon juice. A band at 443nm was seen in particles synthesized using a 4:1 (silver nitrate: lemon juice) ratio. Maximum absorption was observed at 438 nm when the volume of lemon juice to silver nitrate solutions was 2:3. Absorption maximum shifts occurred most noticeably for 1:4 ratios, where they occurred at 434nm. Particle size, shape, aggregation state, and the surrounding dielectric media can all cause a spectrum shift towards the red or blue end of the spectrum, respectively [28]. As the amount of lemon juice in the medium grew, a blue shift was detected. Transmission electron microscopy revealed spherical and spheroidal silver nanoparticles with a size of less than 50 nm [27].

3.3. *p*H

The growth of silver nanoparticles varies with pH of the solution, and the pH of the reaction mixture has a major impact on the nanoparticles' size, shape, and morphology. Scientists have found that the size and texture of a synthesized nanoparticle are affected by the pH of the solution media [29]. Therefore, the pH of the solution media can be used to regulate nanoparticle size. Soni and Prakash [30] showed that the synthesized silver nanoparticle's form and size changed when the pH changed. Green, spherical silver nanoparticles were generated at different pH values, with most particles measuring between 20 and 50 nm in size. Noori and colleagues [26] studied the effect of pH on the size and form of silver nanoparticles created in a green synthesis utilizing *Carica papaya* fruit juice (Table 1). Absorbance increases with increasing pH (from 4 to 7), and decreases with increasing pH (8 and 9). Thus, a pH of 6 was determined to be optimal for the reaction, and it was confirmed that the electrical charges of the bio-components used as capping and stabilizing agents could be altered, thereby affecting the form and size of the synthesized AgNPs. Kiwifruit juice typically has a pH between 3 and 4. Consequently, if kiwifruit juice is abundant, the pH of the reaction solution will drop, leading to the creation of big particles through aggregation. Therefore, the variation in Plasmon absorption of silver nanoparticles implies that the size of the silver nanoparticles was adjusted with the amount of juice, which functions as a controller of nucleation and a stabilizer [20].

3.4. Temperature

When synthesizing silver nanoparticles, it is also important to take temperature into account, as this variable regulates the rate at which the synthetic reaction proceeds. As the temperature rises, the effective collision and frequency factor of the reacting species both increases, leading to a higher reaction rate. According to published research, as the temperature of a silver nanoparticle increases, its mean diameter decreases, causing a bathochromic shift that increases the intensity of the Plasmon band. Even though AgNP synthesis may be quick early in the reaction, this does not indicate that the system is operating at an optimal temperature; on the contrary, operating at a low temperature emphasizes the ability of the reducing and stabilizing agent [24]. Investigators studied the impact of temperature on the structure of silver nanoparticles formed through biosynthesis, and they found that the creation rate increased with rising temperature. When growing nanoparticles are prevented from clumping together, their size initially decreases. When the temperature is raised to roughly (60 ^{o}C), the crystal grows around the nucleus, reducing absorbance. It was found that the vast majority of Ag nanoparticles had a spherical arrangement [26].

3.5. Time

Time spent in contact, often called reaction time, is a major component in the development of silver nanoparticles. This was achieved by adjusting the duration of the silver nanoparticle production process. The development of silver nanoparticles is typically indicated by a colour shift to yellow or brown. The UV-Vis spectrophotometer is used to keep an eye on things until the optimal wavelength for maximal absorption is reached, resulting in high-quality surface Plasmon resonance (SPR). Peak intensity grows as contact duration lengthens because it is a function of contact time. Because of the blue shift of the adsorption peaks, contact duration is one of the characteristics that control the size of silver nanoparticles. The slow conversion of silver ion (Ag^+) to zero-valent silver (Ag^0) nanoparticles causes the SPR band to expand between 0 and 20 minutes (during the early stage). The longer the contact period, the more Ag^+ is transformed to Ag^0, leading to better Plasmon band development. However, as the contact time is extended, the absorbance strength and wavelength diminish, indicating that the silver nanoparticles are beginning to aggregate and decreasing in size [20]. Prathna and his co-authors investigated different time scales to establish an appropriate minimum for interaction. It was discovered that silver nanoparticles can only be formed after a connection lasting at least 4 hours [27].

3.6. Fruit juice

The orange juice may have an impact on the shape and size of the silver nanoparticles depending on the components in the orange juice. Orange juice contains citric acid, which is capable of reducing silver ions to silver nanoparticles due to its antioxidant properties [31]. This reaction can lead to the formation of a variety of silver nanoparticles with different sizes and shapes. The orange juice may also contain proteins, sugars, and surfactants that are capable of coating the silver nanoparticles and further altering their shape and size. Prasad *et el*. (2011) used orange juice as a reducing agent for the preparation of silver nanoparticles and reported a spherical shape with a few aggregations of silver nanoparticles in a range of 9 to 25 nm, as shown in Table 1. The Berry juices play an important role in affecting the shape and size of silver nanoparticles. The acids in the Berry juices can help to reduce the surface tension of the silver nanoparticles, which will lead to their transformation into more spherical shapes and smaller sizes. This can be attributed to the presence of species such as polyphenols and flavonoids in the Berry juices, which are known to act as reducing agents. Additionally, Berry juices possess antioxidant properties, allowing them to react with the silver nanoparticles, causing a further decrease in size [32]. Moreover, the presence of polyphenols and flavonoids, which act as reducing agents, and the antioxidant properties of the Berry juices play a role in further decreasing the size of the nanoparticles. Therefore, the uniform shape and particle size in the range of 10 to 100 nm silver nanoparticles has been observed by using berry juice [33]. The grape juice acts as a reducing agent for the silver nanoparticles, which will reduce their size and change their shape. The decrease in size is due to the fact that the grape juice reduces the silver ions to silver atoms, making them smaller and more rounded. The shape of the silver nanoparticles can also be affected by the presence of other substances in the grape juice, such as tannins or polyphenols. Tannins can act as stabilizing agents that help keep the silver nanoparticles in their spherical shape, while polyphenols can cause the particles to take on different shapes [34]. The impact of kiwi juice on the shape and size of silver nanoparticles will vary depending on the concentration and type of kiwi juice used. In general, kiwi juice can be used to reduce the aggregation of silver nanoparticles and prevent them from clumping together, resulting in a more uniform shape and size. The antioxidant properties of kiwi juice are also believed to help stabilize the silver nanoparticles, making them less sensitive to environmental conditions [35]. Such as, kiwi juice can contribute to the maintenance of silver nanoparticle size and shape. The Limon juice has a significant impact on the shape and size of silver nanoparticles. The citric acid present in the Limon juice causes the silver ions to become insoluble [36]. This decreases the level of agglomeration of the silver nanoparticles, meaning that they form more uniform shapes and sizes. Additionally, the pH of Limon juice creates an environment that encourages the formation of smaller silver nanoparticles [37]. The Limon juice also helps to reduce the rate at which silver nanoparticles oxidize, making them more stable [38]. The pomegranate juice has an impact on the shape and size of silver nanoparticles due to the natural presence of citric and gallic acid [39]. These acids have antibacterial properties, which can help reduce the size of silver nanoparticles. Additionally, the antioxidants present in pomegranate juice can react with the silver nanoparticles to create a more uniform shape and size. Ultimately, this process helps stabilize the silver nanoparticles and makes them easier to work with for industrial purposes [40]. The morphology of silver nanoparticles depends on the quantity of pomegranate juice. Rashmi Madhuri *et al*. (2015) reported using different quantities of pomegranate juice to synthesize silver nanoparticles in spherical shape using three milliliters, oval shape using one milliliter, half milliliter rod shape, and eight-milliliter flower shape. It can be indicated that the quantity of reducing agents has an impact on the morphology of silver nanoparticles, as illustrated in Table 1. The Cashew apple juice has been shown to have a significant impact on the shape and size of silver nanoparticles. Studies show that when Cashew apple juice is used as a reducing agent, it helps to reduce the particle size and causes a significant change in the size distribution of the silver nanoparticles Due to chemical constituents of Cashew apple juice such as alkaloids, flavonoids, phenolic compounds, gum and mucliages, carbohydrates, glycosides, proteins, phytostroles, and tannins [41, 42] rapidly reduce the ionic strength of silver ions.. The Cashew apple juice also affects the shape of the silver nanoparticles, resulting in a higher percentage of spherical particles versus irregular shapes. This has been attributed to the presence of certain compounds in the juice, such as polyphenols [43], which activate the deposition process and stabilize the silver nanoparticles with the spherical shape and densely packed with average particle size of 45 nm [44]. The impact of pear juice on the shape and size of silver nanoparticles is that it can affect the growth of the particles. The presence of organic acids such as phenolic, and ascorbic compound [45] in the juice, along with the chelating effect of certain polysaccharides, can alter the electrostatic properties of silver ions and encourage the formation of either small, spherical particles or larger, rod-like particles. By adjusting the pH of the solution and controlling other growth parameters such as temperature and concentration, it is possible to control the size and shape of the silver nanoparticles [16]. The carambola juice can have a significant impact on the shape and size of the silver nanoparticles. The juice contains organic acids and antioxidants [46], which can interact with the surface of the nanoparticles and change their properties. The pH of the juice can also influence the particle size and shape, causing them to form smaller and more irregular shapes. Additionally, the presence of natural compounds such as citric acid may act as reducing agents and affect the reactivity of the nanoparticles, leading to changes in the shape and size [47], as shown in Table 1 and Figure 1.

Table 1. Impact of fruit juice on the morphology of silver nanoparticles.

Fruit juice	Characterization technics	Shape	Particle size	Ref.
Orange	TEM	Spherical	9-25 nm	[17]
Berry	TEM	Spherical	50 nm	[18]
Grape	SEM	Spherical	10-30 nm	[19]
Kiwi	TEM	Spherical	2-25 nm	[20]
Limon	TEM	Spherical	25-50 nm	[21]

Cashew Apple	SEM	Spherical	45 nm	[44]
Pear	TEM	Spherical	10 nm	[16]
Carambola	TEM	Spherical	10-40 nm	[24]
Pomegranate	SEM	Spherical	50 nm	[23]
		Oval	100 nm	[23]
		Rod	100 nm	[23]
		Flower	50 nm	[23]
Carica papaya	SEM	Spherical	500 nm	[26]
Lantana camara;	TEM	Spherical	12.5 -13 nm	[48]
Kei-apple	TEM	Spherical, with a few oval	12-53 nm	[49]
Elaeagnus umbellata	SEM	Spherical	12 nm	[50]
Phoenix dactylifera	TEM	Spherical	20-100 nm	[51]
Strawberry	TEM	Spherical	7-65 nm	[52]
Tamarind	TEM	Spherical	5-12 nm	[53]
Ficus carica	SEM	Spherical	20-25 nm	[54]

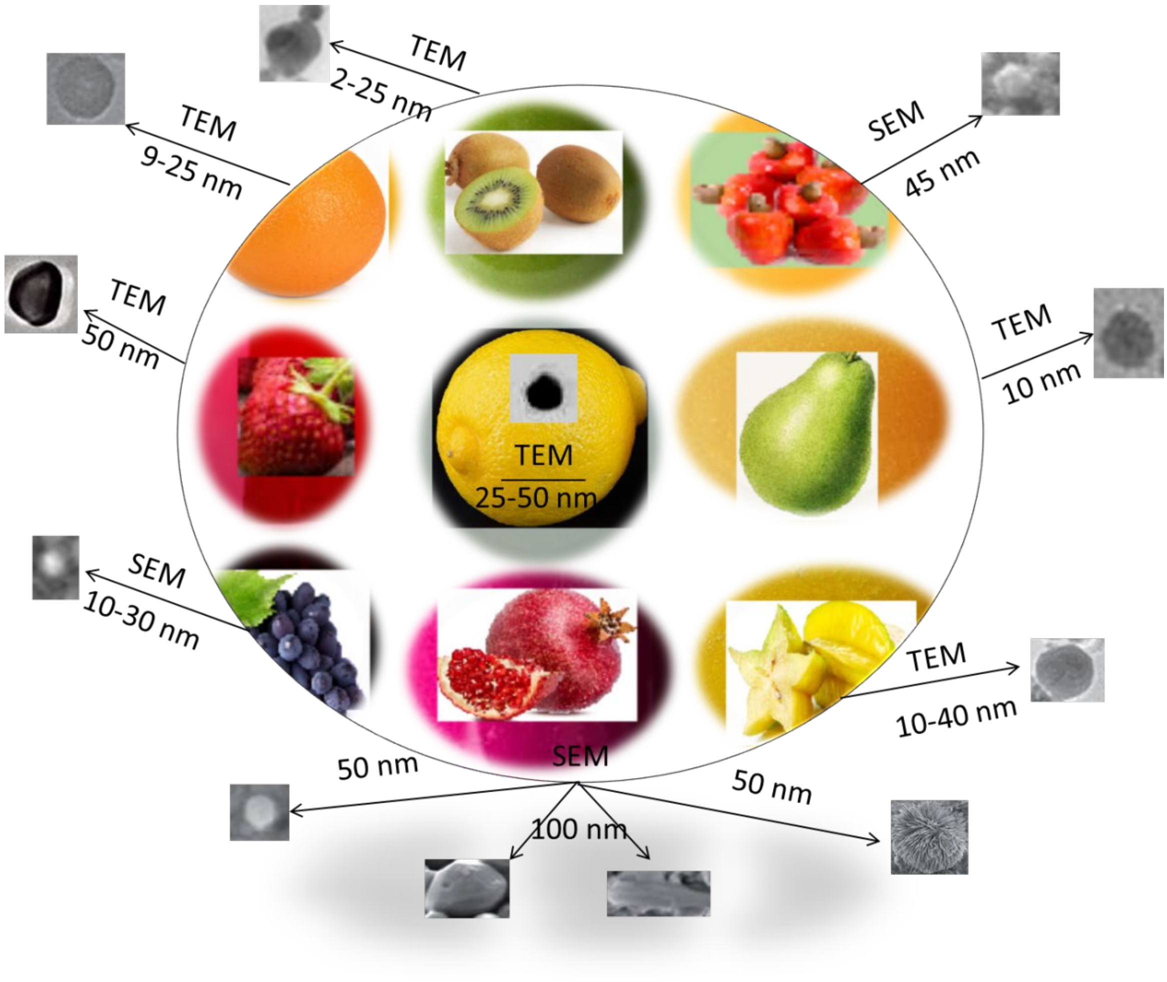

Figure 1. Morphology of silver nanoparticles using fruit juices as reducing agents.

Conclusions

This review thoroughly examines the effect of fruit juice on the morphology of silver nanoparticles. Our findings indicate that fruit juice, due to its rich array of reducing agents, effectively regulates the shape and size of nanoparticles during synthesis. We identified several key factors that influence the final morphology, including the type of fruit, concentration, mixing time, pH, silver nitrate ratio, and temperature. By using fruit juice as a reducing agent, we reveal new possibilities for manipulating nanoparticle morphology, which has significant implications across various fields. In healthcare, the controlled synthesis of silver nanoparticles with specific shapes and sizes can enhance their effectiveness in targeted drug delivery and imaging. In electronics, tailoring nanoparticle morphology can improve device performance and efficiency. In catalysis, adjusting nanoparticle shape and size can optimize catalytic activity for different reactions. Overall, this review highlights the potential of utilizing fruit juice as a reducing agent in nanoparticle synthesis to achieve precise control over their morphologies.

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