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Nano Silver Fluoride Preparation as an Anti-Caries Agent: A Scoping Review

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ABSTRACT

Nano Silver Fluoride (NSF) is increasingly recognized as a potential non-invasive agent for caries management. However, its synthesis methods and formulation variables may significantly impact clinical performance. This scoping review aimed to map current evidence on NSF synthesis and to identify factors influencing its anti-caries activity. Following the Joanna Briggs Institute methodology, a systematic search was conducted in PubMed, Scopus, Web of Science, and Cochrane Library. Eligible studies were those reporting the preparation of NSF specifically for dental caries prevention. Of 734 articles screened, nine fulfilled the inclusion criteria. Data were extracted using a standardized form covering synthesis methods, nanoparticle characteristics, formulation parameters, and reported outcomes. Most studies employed chemical reduction techniques, typically using silver nitrate as the precursor, sodium borohydride as the reducing agent, and stabilizers such as chitosan or fluoride. The resulting nanoparticles were predominantly spherical, ranging from 3.2 to 16 nm in size, with concentrations between 400 and 33,989 ppm. Across studies, the anti-caries effect of NSF was linked to particle size, fluoride concentration, stabilizer choice, and synthesis route, each influencing stability and antibacterial activity. NSF demonstrates consistent anticaries potential and aesthetic advantages over traditional fluoride agents. While comparable outcomes have been observed across different synthesis routes, variations in formulation and characterization highlight the need for standardized protocols and comprehensive in vivo investigations to ensure reproducibility and optimize clinical translation.

INTRODUCTION

Dental caries remains one of the most prevalent chronic diseases worldwide, affecting individuals across all age groups (Featherstone et al., 2021). Despite advances in preventive and restorative dentistry, the burden of untreated dental caries in primary and permanent dentitions continues to pose a major public health challenge, particularly in underserved and low-income populations (Prakash et al., 2022). Traditional fluoride therapies, such as sodium fluoride (NaF) and silver diamine fluoride (SDF), have long been applied

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in caries prevention and management (Prakash et al., 2022). However, while SDF is effective in arresting caries, its major drawback is the permanent black staining of lesions, which reduces its acceptability, particularly in anterior teeth and among paediatric patients (Zaffarano et al., 2022).

In response to this drawback, Dos Santos and colleagues (2014) synthesized Nano Silver Fluoride (NSF), marking a key turning point in cariology (Dos Santos et al., 2014). Their formulation combined silver nanoparticles for antimicrobial activity, chitosan as a biocompatible stabilizer and vehicle, and fluoride for remineralization potential (Dos Santos et al., 2014). Using a chemical reduction method in which silver nitrate was reduced and stabilized by chitosan, they produced a stable colloidal solution of nanosized silver particles that maintained antibacterial effectiveness without inducing dental staining (Dos Santos et al., 2014). Unlike SDF, the silver nanoparticles in NSF do not form oxides upon exposure to oxygen, preventing discoloration after application (Targino et al., 2014). Early studies confirmed NSF's potent antimicrobial action against *Streptococcus mutans* and *Lactobacillus spp.*, with minimum inhibitory and bactericidal concentration values of 33.54 μg/ml and 50.32 μg/ml, respectively (Targino et al., 2014). The MIC represents the lowest concentration of NSF required to inhibit visible bacterial growth, while the MBC indicates the concentration needed to completely eliminate bacterial cells. These values are comparable or even lower than those reported for conventional fluoride-based or silver-containing agents, suggesting that NSF achieves potent antimicrobial efficacy at relatively low concentrations (Targino et al., 2014; Pushpalatha et al., 2022). Furthermore, NSF remains a stable yellow colloidal solution with long-term physicochemical stability during storage, enhancing its practicality for clinical and community use (Tirupathi et al., 2019).

Following this initial synthesis, researchers have explored various methods to optimize NSF production, leading to significant diversity in formulation. Differences in silver precursors, reducing agents, and stabilizers have resulted in nanoparticles with variable size, morphology, fluoride concentration, and stability (Ghorbani et al., 2011; Woo et al., 2008). More recently, commercial and biologically synthesized NSF formulations have incorporated modifications such as the use of natural reducing agents or plant extracts to improve safety and biocompatibility (Ghorbani et al., 2011). However, this methodological variability has also contributed to a lack of standardization across studies. Emerging evidence indicates that these variations in synthesis directly influence the anticaries performance of NSF. For example, randomized controlled trials have demonstrated that higher NSF concentrations (600 ppm) result in significantly greater caries arrest rates than lower concentrations (400 ppm) in primary molars (Arnaud et al., 2021). Likewise, smaller nanoparticle sizes (<10 nm) have been associated with enhanced antibacterial activity due to increased surface area and greater silver ion release, while differences in stabilizing agents, such as chitosan versus fluoride-based compounds, affect particle stability and ion bioavailability (Ghorbani et al., 2011; Yin, Zhao, et al., 2020). These findings suggest that variations in synthesis protocols are not trivial but can substantially impact both the antibacterial potency and clinical outcomes of NSF. Consequently, understanding how synthesis parameters influence its effectiveness is crucial for optimizing its formulation and ensuring reproducibility across studies.

Given the heterogeneity and fragmented nature of the existing literature, a scoping review is warranted to systematically map current evidence on NSF synthesis and identify key formulation variables influencing its anticaries activity. The scoping review approach, guided by the Joanna Briggs Institute (JBI) methodology, allows comprehensive exploration of synthesis methods, nanoparticle characteristics, and their relationship with anticaries outcomes, rather than limiting analysis to a single intervention. Accordingly, this review aims to assess the extent of published literature on NSF synthesis and to identify the formulation variables that may influence its effectiveness as an anticaries agent. The review question was: What methods have been used to synthesize NSF for use as an anticaries agent, and what key formulation variables have been reported? This review considered studies describing the synthesis of NSF (Concept), intended for anticaries applications in children and adults (Population), within the context of dental caries prevention (Context).

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METHOD

This scoping review was conducted following the methodological framework outlined in the Joanna Briggs Institute (JBI) Manual for Evidence Synthesis (Peters et al., 2020) and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines (Trico et al., 2018). The JBI framework guided the methodological approach, while PRISMA-ScR ensured transparent and standardized reporting. The completed PRISMA-ScR checklist is submitted as supplementary material. A review protocol was developed prior to data collection but was not formally registered on any public database.

Eligibility criteria were defined a priori to ensure inclusion of studies that directly investigated the synthesis and anticaries application of NSF. Only primary in-vitro or in-vivo studies that provided explicit details on NSF formulation, such as the precursors, reducing or stabilizing agents, and fluoride components used were included. Studies were also required to evaluate at least one relevant outcome, including antibacterial activity, remineralization potential, fluoride release, or physicochemical characterization using human dental tissues. Exclusion criteria included review articles, conference abstracts, guidelines, animal studies, or papers involving non-dental applications of NSF. Articles that lacked sufficient methodological detail to reproduce the synthesis process, as well as non-English or inaccessible full-text publications, were excluded. Table 1 summarizes the refined inclusion and exclusion criteria.

Table 1. The inclusion and exclusion criteria.

Inclusion	Exclusion
Primary in vitro or in vivo experimental studies that investigated the synthesis, characterization, or application of NSF as an anticaries agent.	Review articles, conference abstracts, guidelines, or theses.
Studies describing methods of NSF synthesis or formulation, including details of precursors, reducing agents, stabilizers, or fluoride components.	Studies using silver nanoparticles or other fluoride formulations without clear description of NSF synthesis or composition.
Studies involving human teeth (extracted or in situ) to assess antimicrobial or remineralization properties.	Studies conducted exclusively on animal models or involving non-dental applications of NSF.
Studies reporting antibacterial activity, fluoride release, physicochemical characterization, remineralization potential, or caries-preventive outcomes of NSF.	Articles lacking sufficient methodological detail to reproduce the NSF synthesis protocol.
Peer-reviewed articles published in English with full-text availability up to 20 December 2024.	Non-English publications or inaccessible full-text articles.

A comprehensive literature search was conducted to identify all relevant studies published up to 20 December 2024. The electronic databases searched included PubMed, Scopus, Web of Science, and the Cochrane Library. To minimize publication bias and capture non-indexed material, grey literature sources, including Google Scholar, OpenGrey, and ProQuest Dissertations & Theses Global, were also screened. Reference lists of all included studies were manually reviewed to identify additional eligible publications.

The search strategy was systematically developed using a combination of controlled vocabulary (MeSH terms) and free-text keywords. Preliminary searches in PubMed were conducted to identify relevant indexing terms, which were refined into a logic grid using Boolean operators (AND, OR) and truncations. The final search combined concepts related to NSF, its synthesis, and its anticaries use. Keywords and MeSH terms used included: “nano silver fluoride,” “silver fluoride nanoparticles,” “fluoridated silver nanoparticles,” “silver nanoparticles with fluoride,” “dental caries,” “caries prevention,” “anticaries agent,” “topical fluoride,” “remineralization,” “synthesis,” “formulation,” “preparation,” and “characterization.” No publication year limits were applied. Filters were restricted to English-language studies involving

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human teeth in either in-vitro or in-vivo experiments. Table 2 presents the detailed search strategy for each database.

Table 2. Search string used.

Database	Search String
PubMed	((“fluoridated silver nanoparticle*”) OR (“fluoridated AgNP*”) OR (“nano silver fluoride”)) AND ((“caries”) OR (“tooth decay”) OR (“demineralisation”) OR (“anticari*”))
Scopus	TITLE-ABS-KEY(((fluoridated AND silver AND nanoparticles) OR (fluoridated AND AgNPs) OR (nano AND silver AND fluoride)) AND ((caries) OR (tooth decay) OR (demineralisation) OR (anticaries)))
Web of Sciences	((“fluoridated silver nanoparticles”) OR (“fluoridated AgNPs”) OR (“nano silver fluoride”)) AND ((“caries”) OR (“tooth decay”) OR (“demineralisation”) OR (“anticaries”))
Cochrane Library	(“nano silver fluoride” OR “silver fluoride nanoparticles” OR “fluoridated silver nanoparticles”) in Title, Abstract, or Keywords

All search results were imported into Mendeley Reference Manager for organization and duplicate removal. Two independent reviewers (NSR and APV) screened titles, abstracts, and full texts using the defined inclusion criteria. A pilot calibration exercise involving five randomly selected studies was conducted to ensure consistency in eligibility application. Any disagreements between reviewers were resolved through discussion; unresolved cases were arbitrated by a third reviewer (ASH).

Data were extracted independently by both reviewers using a standardized extraction form developed in accordance with the JBI template. Extracted information included the following domains:

1. Study characteristics: author(s), year of publication, study type (*in vitro*, *in vivo*, or clinical trial), and sample details (number and type of teeth or participants).
2. NSF formulation details: synthesis method (chemical, biological, or commercial), type and concentration of precursors, reducing and stabilizing agents, fluoride source and concentration, and resulting nanoparticle size.
3. Validation methods: tools and techniques used for characterization or performance testing (e.g., TEM, UV-Vis spectroscopy, antibacterial assays).
4. Study outcomes: key findings related to antibacterial efficacy, remineralization, fluoride release, stability, or clinical caries arrest effectiveness.
5. Comparative context: control materials or agents used for comparison (e.g., SDF, NaF varnish, n-HAP, or water).

These extracted domains correspond to the summarized information presented in Table 3 (Study and Formulation Summary) and Table 4 (Synthesis Method and Composition Details). In accordance with JBI scoping review methodology, no formal critical appraisal or quantitative meta-analysis was conducted, as the objective was to map and describe the breadth of available evidence rather than evaluate study quality or estimate pooled effects.

Extracted data were organized into summary tables and analyzed descriptively. Heterogeneity across studies was qualitatively assessed by systematically comparing variations in synthesis parameters, including the type and concentration of precursors, reducing and stabilizing agents, synthesis temperature and duration, fluoride incorporation methods, nanoparticle size, and validation techniques. These methodological differences were charted and analyzed narratively to identify patterns and inconsistencies among studies. The degree of heterogeneity was interpreted based on the range and variability of reported synthesis protocols and material compositions rather than statistical metrics.

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RESULTS

A total of 732 records were identified through systematic database searches (PubMed, Scopus, Web of Science, and Cochrane Library) with an additional 2 records from grey literature. A total of 734 records were retrieved (PubMed = 303, Scopus = 150, Web of Science = 251, Cochrane = 30). After removing 57 duplicates, 677 unique records remained for screening. Of these, 649 were excluded for not meeting the inclusion criteria (23 review papers and 626 studies deemed outside the review scope). Subsequently, 29 full-text articles were assessed for eligibility, and 20 were excluded due to reasons such as unavailability of full text (n = 5), unclear methodology (n = 7), or lack of relevance (n = 8). Ultimately, nine studies met the inclusion criteria and were included in this scoping review. The study selection process is summarized in Figure 1 (PRISMA-ScR flow diagram), which illustrates the number of records identified, screened, excluded, and included in accordance with PRISMA-ScR guidelines.

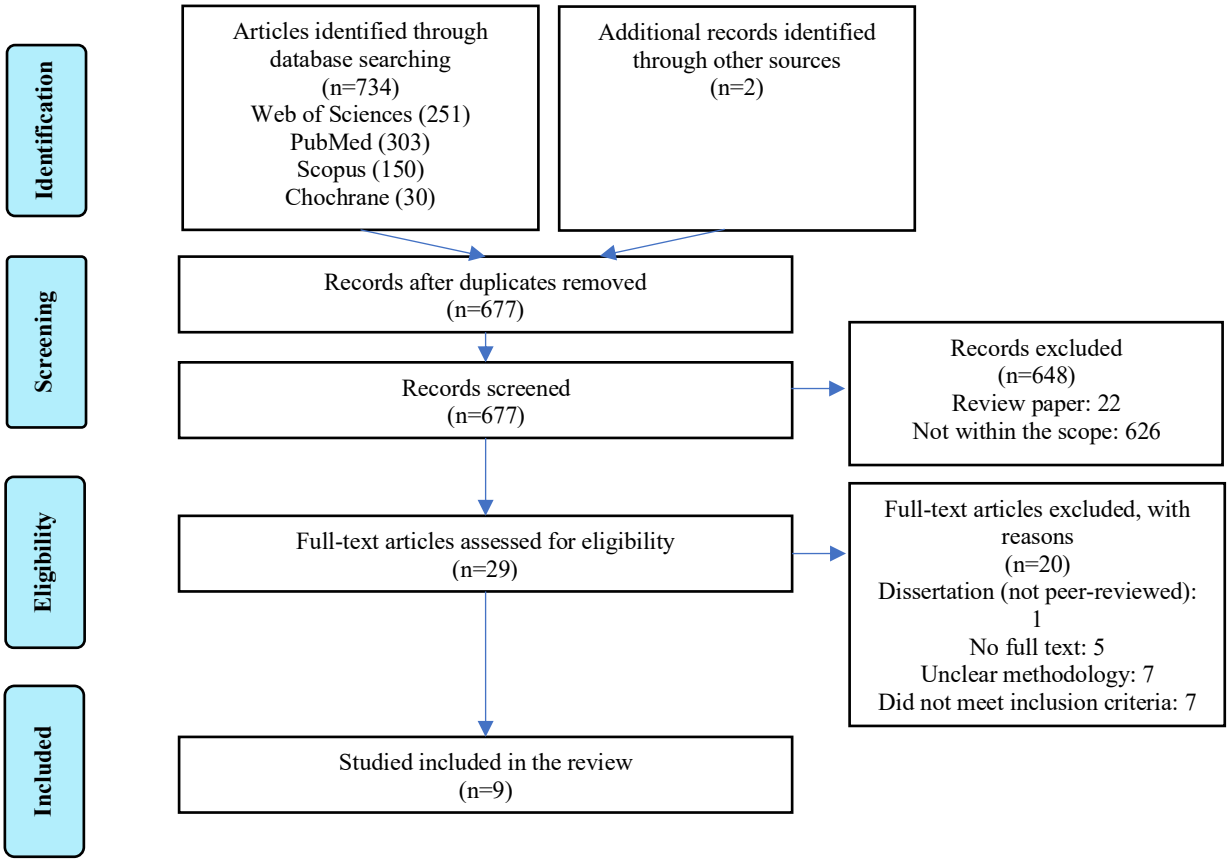

Fig. 1. PRISMA-ScR flow diagram illustrating the study selection process.

The main characteristics of the included studies are presented in Table 3. The included studies were published between 2014 and 2022, showing a gradual increase in publications between 2017 and 2022 (n = 8). Among the included studies, five were in vitro experiments and four were randomized controlled trials (RCTs). Three studies (Dos Santos et al., 2014; Nozari et al., 2017; Tirupathi et al., 2019) specifically investigated primary teeth, while (Soekanto et al., 2017; Yin, Zhao, et al., 2020) involved permanent teeth and the remaining studies did not specify tooth type. Only five studies reported characterization of NSF using analytical techniques such as Transmission Electron Microscopy (TEM), Scanning Electron Microscopy (SEM), and Ultraviolet–Visible (UV-Vis) spectroscopy. Control materials varied among

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studies and included water (Dos Santos et al., 2014), SDF (Soekanto et al., 2017; Tirupathi et al., 2019; Al-Nerabieah et al., 2020; Favaro et al., 2022), NaF varnish (Nozari et al., 2017; Yin, Yu, et al., 2020; Yin, Zhao, et al., 2020), serum n-HAP (Nozari et al., 2017) and propolis fluoride varnish (Soekanto et al., 2017). Most authors concluded that NSF demonstrated promising anti-caries potential, showing comparable or superior performance to conventional fluorides without causing discoloration, and recommended its use in children.

Different synthesis procedures and precursor types were reported across studies (Table 4). NSF synthesis methods included chemical (n = 3), commercial (n = 3), and biological (n = 3) approaches. The majority (n = 5) used silver nitrate ($AgNO_3$) as the silver precursor, while others used commercial nano-silver powder (n = 3) or silver acetate (n = 1). The reducing and stabilizing agents varied, including sodium borohydride, glucose, epigallocatechin gallate, ethylene glycol, green tea extract, *Moringa oleifera* extract, chitosan, gelatin, and polyvinylpyrrolidone (PVP). The diversity of these reagents resulted in a wide nanoparticle size range (2–30 nm), though all were reported as spherical in shape. Most studies (n = 8) incorporated sodium fluoride (NaF) as the fluoride source, while one study (Soekanto et al., 2017) used ammonium fluoride.

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Table 3. Study and formulation summary.

N	Authors / Year	Type of Study	Materials	Method of synthesis	Final concentration	Validity tools	Number and type of teeth	Control	Conclusion
1	Santos et al., (2014)	RCT	- Silver nitrates (4 ml, 0.012 M) - Chitosan solution (60 ml) - sodium borohydride - sodium fluoride	Chemical synthesis	NSF: 33,989.8 µg/mL Chitosan: 28,585 µg/mL Ag^{+}: 376.5 µg/mL NaF: 5028.3 µg/mL	**TEM**: 3.2 +/- 1.2 nm spherical in size	60 children with dentinal caries of primary teeth (130 teeth)	Water	Within 7 days, 81% of teeth treated with NSF treatment exhibited arrested caries progression. The NSF successfully controlled caries in children from underprivileged neighborhoods.
2	Nozari et al., (2017)	In-vitro study	- NSF powder (Sigma-Aldrich) - Distilled water	Commercial synthesis	Ag^{+}: 376.5 µg/mL	NA	80 sound primary anterior teeth	NaF varnish, serum n-HAP, and control	NSF exhibits the highest remineralization capacity among the materials assessed. Consequently, NSF and n-HAP serum may serve as alternatives to NaF varnish.
3	Soekanto et al., (2017)	In-vitro study	- Silver nitrate - Gelatine 5mL - Glucose - Ammonium fluoride 4.4g	Chemical synthesis	NSF in different concentration (3.16%, 3.66%, and 4.16%)	NA	90 dentin discs of extracted premolars	SDF and propolis fluoride	Unlike SDF, the NSF and PPF fluoride-based varnishes in this study released calcium, phosphate, and fluoride ions, highlighting their potential as effective anti-cariogenic agents.
4	Tirupathi et al., (2019)	RCT – double-blind	- Silver nano-particle powder 0.5 grams (containing PVP) - NaF varnish (10 mL of 22,600 ppm)	Commercial synthesis	5% NSSF	NA	159 carious primary molars in 50 children	SDF	Annual application of 5% NSSF is as effective as or superior to 38% SDF in preventing dentinal caries progression in primary molars, supporting its recommendation for use in children.
5	Yin, Yu, et al., (2020)	In vitro study	- 0.5 mL $AgNO_3$ (50 mM) - 20 mL chitosan (10 mg/mL) - 0.2% (v/v) acetic acid - 1mL epigallocatechin gallate (50 mM) - NaF	Biological synthesis	AgNPs 4000ppm and 5% NaF solution (22,600 ppm)	**Uv-Vis**: peak at 402 nm SPR **TEM**: 17.38 ± 7.26 in diameter	30 molars	NaF 5%	AgNPs within the NaF solution successfully remineralize dentine cavities without producing discoloration.

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6	Yin, Zhao, et al., (2020)	In vitro study	- 20 mg polyethylene glycol thiol - 40 mg silver acetate - 400-mL ethanol - NaF (2.5%, 11,310 ppm)	Chemical synthesis	PEG-AgNPs solution of various concentration (12,800, 6400, 1600, and 400 ppm)	**Uv vis**: no show of any characte-rristic (SPR) band **TEM**: 2.56 ± 0.43 nm monodis-persed spherical	18 slices of enamel and dentin of the human third molar	12,800, 6400, 1600, and 400 ppm of PEG-AgNPs solution & NaF	A biocompatible NaF solution with PEG-AgNPs was developed, demonstrating antibacterial activity against *Streptococcus mutans* without causing tooth staining, making it a potential anti-caries agent.
7	Al-Nerabieah et al., (2020)	RCT – single-blinded	- 60 mL of green tea extract - 500 mL deionized water - Potassium carbonate (pH 10) - 20 ml of the 1mM $AgNO_3$ - NaF (10,104 ppm)	Biological synthesis	NA	**SEM**: 4 nm average of spherical shape	63 children with 164 active carious lesions	SDF	Both SDF and NSF-GTE demonstrated cariostatic efficacy in primary teeth, with NSF-GTE proving non-inferior to SDF.
8	Favaro et al., (2022)	In-vitro study	- colloidal silver nanoparticles solution (0.04%) - ethylene glycol - poly-vinylpyrrolidone - 2% NaF	Commerc-ial synthesis	NA	**TEM**: 7–30 nm spherical size	12 enamel blocks of human teeth	SDF	NSF exhibited long-term stability, antimicrobial potential, and biocompatibility, while demonstrating both superficial and deep remineralization without causing enamel staining.
9	Kadhem & Haidar, (2022)	RCT-single-blinded	- 10 mL *Moringa Oleifera* extract - 100 mL of 1 mM $AgNO_3$ - NaF (10,104 ppm)	Biological synthesis	NSF-MOLE; 0.25mg/mL F + 60mg/mL Ag	NA	83 children with 138 carious lesions	MI varnish and FluoroDose varnish (5% NaF)	This study demonstrated that *M. oleifera*-based NSF is effective in arresting dental caries when applied directly to the lesion.

NA – not available, RCT – Randomized Controlled Trial, TEM – Transmission Electron Microscopy, n-HAP – nano-hydroxyapatite, PPF – propolis fluoride varnish, PVP - Polyvinylpyrrolidone, NSSF – Nano-silver incorporated Sodium Fluoride, $AgNO_3$- Silver Nitrate, AgNPs – Silver Nanoparticles, Uv-Vis – Ultra-violet Visible, PEG-AgNPs –Polyethylene Glycol-Silver Nanoparticles, NSF-GTE – Nano Silver Fluoride with Green Tea Extract, NSF-MOLE – NSF using *Moringa oleifera* leaf extracts, MI – Minimum Intervention, ppm – part per

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Table 4. Synthesis method and composition details.

N	Authors	Method	Silver precursor	Reducing agent	Stabiliser (surfactant)	Size range (nm)	Fluoride agent
1	Dos Santos et al., (2014)	Chemical synthesis	Silver nitrate	Sodium borohydride	Chitosan	3.2 ± 1.2	NaF: 5028.3 µg/mL
2	Nozari et al., (2017)	Commercial synthesis	NSF powder	NA	NA	NA	NA
3	Soekanto et al., (2017)	Chemical synthesis	Silver nitrate	Glucose	Gelatine	NA	Ammonium Fluoride: 4.4g
4	Tirupathi et al., (2019)	Commercial synthesis	Silver nano-particle powder	NA	Polyvinyl-pyrrolidone	NA	NaF varnish (10 ml of 22,600 ppm)
5	Yin, Yu, et al., (2020)	Biological synthesis	Silver nitrate	Epigallocate-chin gallate	Chitosan	17.38 ± 7.26	NaF (5%, 22,600 ppm)
6	Yin, Zhao, et al., (2020)	Chemical synthesis	Silver acetate	Poly-ethylene glycol	Poly-ethylene glycol	2.56 ± 0.43	NaF (2.5%, 11,310 ppm)
7	Al-Nerabieah et al., (2020)	Biological synthesis	Silver nitrate	Green tea extract	NA	4 (average)	NaF (10,104 ppm)
8	Favaro et al., (2022)	Commercial synthesis	Colloidal silver nano particles solution	Ethylene glycol	Polyvinyl-pyrrolidone	7–30	NaF (2%)
9	Kadhem & Haidar, (2022)	Biological synthesis	Silver nitrate	*Moringa Oleifera* extract	*Moringa Oleifera* extract	NA	NaF (10,104 ppm)

NA – not available, ppm – part per million

DISCUSSION

This scoping review systematically mapped existing evidence on the synthesis methods and anticaries effectiveness of NSF. Across the included studies, NSF consistently demonstrated caries-arresting potential comparable to or greater than conventional agents such as SDF and NaF varnish, with the added advantage of avoiding the black staining typically associated with SDF (Espindola-Castro et al., 2020). However, the review revealed substantial heterogeneity in synthesis protocols, precursor types, and characterization practices, emphasizing the need for standardized and validated procedures.

Chemical synthesis remains the most common approach for producing silver nanoparticles (AgNPs) in NSF formulations (Fernandez et al., 2021). This method typically involves a silver precursor, a reducing agent, and a stabilizer (Fernandez et al., 2021). Strong reducing agents such as sodium borohydride produce smaller, more uniform nanoparticles, whereas mild reducing agents yield irregular or aggregated particles (Nguyen et al., 2023). Stabilizers like chitosan and polyvinylpyrrolidone prevent agglomeration and enhance dispersion (Khan & Al-Thabaiti, 2022). These factors collectively determine the physicochemical and biological properties of NSF, including particle stability, ion release, and antimicrobial potential.

Biological synthesis provides an eco-friendlier alternative by using plant extracts, fungi, or bacteria as natural reducing and capping agents stabilizers (Duman et al., 2024). Extracts such as *Camellia sinensis* (green tea) and *Moringa oleifera* have been reported to yield stable nanoparticles with antimicrobial properties (Kadhem & Al Haidar, 2022). However, this method faces limitations such as variability in extract composition, seasonal availability, and difficulty achieving monodisperse particles (Kakakhel et al., 2021). Commercially available nanosilver formulations, often marketed as colloidal silver, also vary widely in composition. Some contain ionic rather than nanoparticulate silver, which can markedly alter their antimicrobial effectiveness and cytotoxicity (Kumar & Goia, 2020). Accurate characterization using UV–

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Vis spectroscopy, transmission electron microscopy (TEM), and scanning electron microscopy (SEM) is essential to distinguish true nanoparticles from ionic forms and ensure consistency across studies.

The anticaries action of Nano Silver Fluoride (NSF) arises from the combined effects of silver nanoparticles (AgNPs) and fluoride ions, and in some formulations, the addition of chitosan enhances these effects. Silver nanoparticles disrupt bacterial membranes, interfere with DNA replication, and induce oxidative stress, while fluoride promotes remineralization and inhibits bacterial glycolysis (Targino et al., 2014; Mohamed et al., 2024). In formulations containing chitosan, the polymer provides additional stability, enhances fluoride retention, and improves adherence to tooth surfaces (Fernandez et al., 2021). However, other stabilizers such as polyvinylpyrrolidone (PVP) or polyethylene glycol (PEG) can also maintain nanoparticle stability and dispersion (Khan & Al-Thabaiti, 2022). Therefore, NSF formulations without chitosan are not less effective but may exhibit different handling characteristics and ion release behaviour, depending on the stabilizer used.

The effectiveness of NSF is strongly influenced by nanoparticle characteristics, including particle size, shape, and aggregation state, as these factors determine surface area, ion release rate, and bacterial interaction efficiency (Iravani et al., 2014; Khan & Al-Thabaiti, 2022; Nguyen et al., 2023). Smaller nanoparticles possess a higher surface area-to-volume ratio, facilitating greater silver ion release and more effective bacterial membrane interaction (Ali et al., 2024). Spherical nanoparticles provide uniform reactivity, while irregular or aggregated particles show reduced antimicrobial activity due to decreased available surface area (Nguyen et al., 2023). The choice of stabilizer further modulates performance, chitosan enhances fluoride retention and adherence to tooth surfaces, supporting remineralization while maintaining particle stability (Khan & Al-Thabaiti, 2022). In addition to material variables, formulation parameters such as silver and fluoride concentration, delivery form (varnish, gel, or solution), and frequency of application contribute to clinical outcomes. Optimal formulations should maximize antibacterial and remineralizing effects while minimizing cytotoxicity to surrounding tissues (Dawadi et al., 2021).

Clinically, NSF represents a promising and aesthetically acceptable alternative to SDF, particularly for paediatric and anterior teeth. In vitro and clinical studies have demonstrated that NSF effectively arrests caries in both enamel and dentin. For example, Pushpalatha et al. (2022) reported that 65.21% of dentinal lesions were arrested following topical NSF application. In preschool children, NSF showed comparable efficacy to SDF in caries arrest while maintaining tooth colour (Tirupathi et al., 2019). Compared to NaF varnish, NSF-treated teeth exhibited improved mineral content, surface hardness, and smoothness (Mohamed et al., 2024). These findings indicate that NSF not only arrests carious lesion progression but may also promote enamel integrity and surface remineralization.

This review has several limitations. Only studies published in English were included, which may have excluded relevant data. Variations in study design, sample size, outcome measures, and nanoparticle characterization limited direct comparisons of clinical effectiveness. Additionally, only a subset of studies reported detailed nanoparticle characterization, restricting the ability to fully correlate synthesis methods with clinical outcomes. Future research should standardize NSF characterization and reporting, identify optimal nanoparticle size, shape, and concentration for maximal anticaries activity, and conduct longitudinal clinical trials comparing NSF with other fluoride therapies across diverse populations. Exploring reproducible, eco-friendly biological synthesis methods could further enhance safety and sustainability.

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CONCLUSION

NSF demonstrates consistent anticaries effectiveness comparable to or greater than conventional fluoride agents, while maintaining favourable aesthetics. Despite diverse synthesis methods, the underlying mechanisms of silver–fluoride synergy remain effective across formulations. Variations in nanoparticle characteristics and stabilizers, however, may influence stability and ion release, underscoring the need for standardized synthesis and reporting protocols. Overall, NSF represents a promising and biocompatible alternative for caries management, warranting further clinical validation for broader dental applications.

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

AUTHORS' CONTRIBUTIONS

Nadhirah Sakinah Rosman conducted the research, drafted, and revised the manuscript. Annapurny Venkiteswaran and Alaa Sabah Hussein conceptualised the research idea, developed the study design, provided theoretical guidance, supervised the research progress, and critically reviewed and approved the final manuscript for submission.

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