# Food and Beverage Ingredients Induce the Formation of Silver Nanoparticles in Products Stored within Nanotechnology-Enabled Packaging

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## Background

**Polymer nanocomposites (PNCs)**: Materials in which particles featuring at least one nanoscale dimension (nanofillers) are integrated into a polymer. PNCs have potential applications in food packaging and medical devices.

**Nanofiller release**: Engineered nanomaterials (ENMs) like silver nanoparticles (AgNPs), which are not currently approved for use in the U.S., could transfer from PNC packaging into foods under intended conditions of use, constituting a potential source of human dietary exposure.

**Influential factors:** food chemistry, nanofiller characteristics (size, composition), polymer properties

- Form of released AgNP mass: nanoparticulate versus dissolved Ag ions
- Research predicts that Ag release is driven by surface oxidation of AgNPs, dissolution into $Ag^+$, and diffusion of $Ag^+$ into the food.

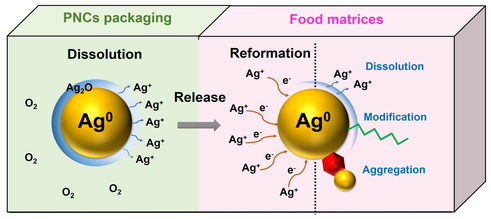
**Limitation**: Most studies assess ENM release into food simulants rather than into foods

- In foods, ENMs may exhibit complex interactions with their environments and transformative behavior that can impact their size, shape, and quantity.

## Hypothesis and Approach

**Hypothesis**:

- Ag ions transferred from AgNP/polymer packaging may be reformed into AgNPs when foods contain redox-active ingredients like some sugars.
- Reformed ENMs may have multiple transformation processes depending on the food environment.




**Approach**:

AgNP-polymer packaging was chosen as a model because:

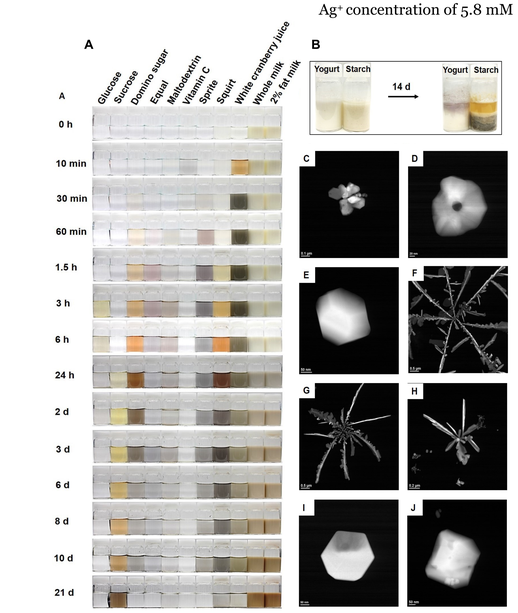
- AgNPs may indicate how redox-active nanoparticles generally behave in foods.
- The use of AgNPs in food packaging has been explored in the primary research literature, suggesting the migration properties should be further evaluated.

1) To explore how Ag ions behave in different foods, we stored solutions of sweeteners, commercial beverages, or liquid foods at different temperatures and $Ag^+$ concentrations.

2) To assess conversion of Ag transferred from packaging to AgNPs, we incorporated lab-synthesized AgNPs into low density polyethylene (LDPE) sachets and analyzed the Ag amount and form within leachates.

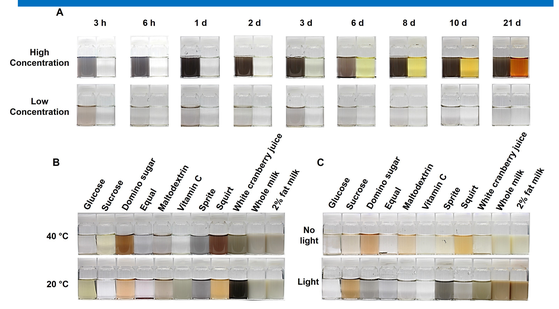
## Formation of AgNPs with sugars

**Food ingredients like reducing sugars or those that form reducing sugars *in situ* transform $Ag^+$ to AgNPs with different morphologies at high $Ag^+$ concentration.**




(A) Aqueous solutions of food ingredients, beverages, and (B) food acquired at different times with $Ag^+$ introduction at 40 °C. (C-J) STEM images of AgNPs formed in (C) glucose, (D, I, J) Domino sugar solutions, and (E) maltodextrin solutions, (F) Sprite, (G) Squirt and (H) white cranberry juice.

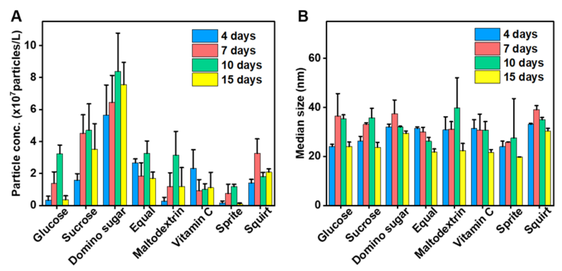
## Factors that influence AgNP formation




(A) Aqueous solutions of maltodextrin (left vial) and vitamin C (right vial) acquired at different times with 5.8 mM of $Ag^+$ introduction and stored at 40 °C. (High concentration of food ingredients represent 9 wt% and low concentration group represents 0.45 wt% of maltodextrin and 0.03 wt% of vitamin C. Aqueous solutions of food ingredients or beverages (B) stored at 40 and 20 °C after 24 hours and (C) stored with light exposure (11 days) or in dark (10 days) with introduction of 5.8 mM $Ag^+$. **AgNPs formation depends on the type and concentration of reducing food ingredient, storage temperature, and light exposure**

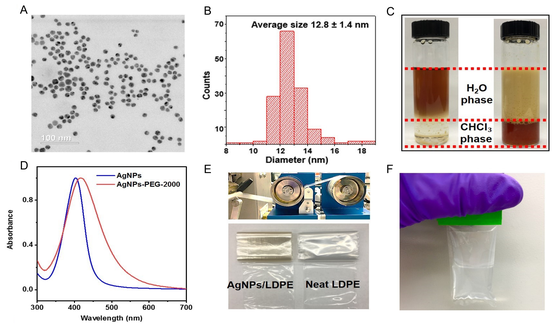
## AgNP formation at low $Ag^+$ concentration

0.25 ppb Ag: **relevant to release from food contact materials**



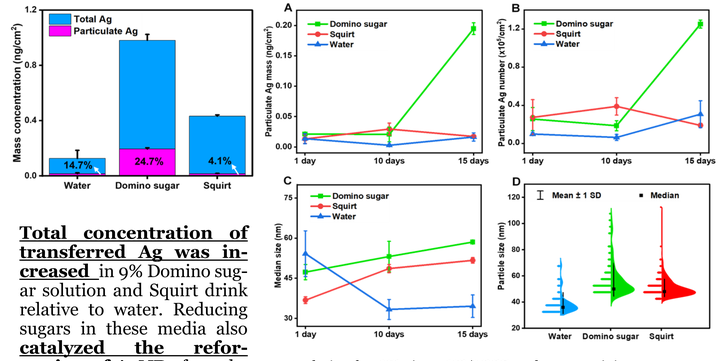

Single particle-ICP-MS analysis of number concentration and size (diameter) of AgNPs formed in food ingredient solutions and commercial beverages after different times post $Ag^+$ introduction. (A) and (B) at 40 °C. **AgNPs form at $Ag^+$ concentrations relevant to food packaging use: AgNPs initially increase in amount and size and then gradually dissolve into ions.**

## AgNPs/LDPE packaging manufacture




(A) STEM image of synthesized AgNPs. (B) Size distribution of AgNPs. (C) Phase transfer of AgNPs to organic solvent by capping with PEG-2000. (D) Normalized UV-Visible spectra of AgNPs in water and chloroform phases. (E) Photograph of AgNPs/LDPE film and neat LDPE film. (F) Photograph of an AgNPs/LDPE sachet filled with Squirt drink.

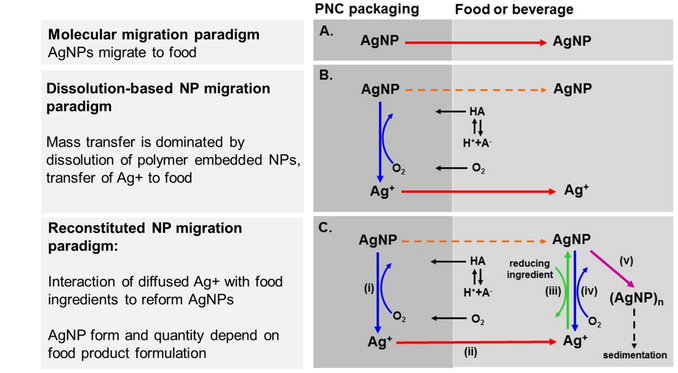
## Speciating transferred Ag in sachets




**Total concentration of transferred Ag was increased** in 9% Domino sugar solution and Squirt drink relative to water. Reducing sugars in these media also **catalyzed the reformation of AgNPs** from the dissolved Ag during storage.

Analysis of AgNPs in AgNP/LDPE sachets containing sweetener-spiked food simulants and beverages. **The particulate Ag mass, number concentration and size in food environments was determined by the rate of both AgNP reformation and transformation (e.g. dissolution)**

## AgNP transfer mechanism: food ingredients




## Conclusions

- Food ingredients with reducing properties or those that can form reducing substances *in situ* may change the Ag exposure profile by inducing AgNP formation from dissolved Ag transferred into foods contacting nanotechnology-enabled packaging.
- The amount and form of AgNPs in foods contacting PNC packaging may depend on food ingredient formulation and silver concentration, storage conditions, light exposure, and pH.
- Interactions between ENMs, the polymer matrix, and food ingredients may need to be considered when estimating potential dietary exposure to nanofillers when PNCs are intended for food packaging applications.

## Acknowledgements and References

OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION

IFSH INSTITUTE FOR FOOD SAFETY AND HEALTH

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