REVIEW ARTICLE

Study of Main Factors Affecting the Leakage of Aluminum into the Food Wrapped in Aluminum Foil During Cooking

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ABSTRACT

Different cooking conditions were examined for aluminum content in food cooked while wrapped with aluminum foil. The influence of each anticipated factor (the acidity of the cooking medium, type of acids normally used in cuisines namely acetic and tartaric acids, various cooking temperatures, influence of the presence of sodium chloride salt, the effect of cooking oil, and the length of time of cooking) was studied thoroughly as a function of aluminum degraded out of the aluminum foils to the medium.

The experimental samples were digested with nitric acid upon fulfillment of examining each factor separately before quantifying aluminum with the sensitive technique of atomic absorption spectroscopy.

The outcomes of the study have shown that the increment in the acidity and the heat of the cooking medium have exhibited a very noticeable effect on the Aluminum content leaked out of the aluminum foil. Nevertheless, the cooking time, the presence of the salt of sodium chloride, and the oil medium compared to the aqueous have exhibited a positive influence by increasing the aluminum leakage out of the foil into the solution.

Keywords: Aluminum content, Aluminum foil, Aluminum leak, Food toxicity, Wrapped food.

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INTRODUCTION

Aluminum (Al) metal is the third most abundant element on earth after silicon and oxygen.[1,2] It makes up 8% of the Soil's shell. Aluminum enters the human body primarily through food, water, airborne dust, antiperspirants, antacids, and allergy shots.[3,4]

High concentrations of aluminum metal were detected in the brains of patients with Alzheimer's disease, and although the function of aluminum absorption in this and other diseases is unclear, the causes of Parkinson's, softening of the bones, and anemia. It is crucial to define the sources clearly.[5-8] However, other severe illnesses like dialysis-induced encephalopathy,cancer, and people with immunodeficiency virus were linked to consumption of foodstuff contamination with aluminum salts as it can accumulate in the gut and various human tissues, causing breast cancer and neurotoxin.[9,10] Despite the approved toxicity of aluminum, it is permitted as a food additive under Health Canada rules, the Canadian Food Inspection Agency (CFIA),[11] and the US Food and Drug Administration (FDA).[12,13] Based on short-term toxicity trials, a provisional tolerance weekly intake (PTWI) of 7 mg/kg body weight is recommended.[14,15] Nevertheless, the inhalation of aluminum compounds, such as those found in the smoke of a cigarette or antiperspirant aerosols, can considerably contribute to daily aluminum intake.[16] Aluminum cookware was found to be associated with aluminum leaching in food, beverages, and water. Partial dissolving of cookware may occur, liberating Al^{3+} as an active cation in foods and beverages, subject to acidity and other variables.[17] Food additives with traces of aluminum have been used in food production for the last century as a hardening agent, raising agent, stabilizer, and coloring agent.[18] It was allowed in some countries like the European Union, United States, New Zealand, Australia, Japan, and China.[19]

About 75% of Al foil is utilized for packaging foodstuff and some other products like cosmetics,[20] thus over 900 thousand tons of foil are produced in Europe alone each year.[21] Packaging and cooking with aluminum became very common in recent years due to its waterproofness, durability to freezing, excellent thermal conductivity, affordability, inertness, and recyclability.[22,23] Customers may be exposed to varying levels of aluminum depending on the types of foods and cooking conditions they practice.[24]

Aluminum is most commonly used in making containers, kitchenette utensils, wrapping foils, and pots.[25] The coating of the outer surface of the aluminum-made objects with Al_2O_3

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thin film protect them from over corrode. Free aluminum reacts in solution with dietary hydrocarbon acids like vinegar (acetic acid), tartaric, and citric acids, as well as other complex counter ions like hydroxyl and fluorides.[26,27]

In general, metal migration from containers is accelerated by the acidity of some diets; for instance, liquors, lemon juice, and berries make aluminum more soluble.[28-30]

Currently, inductively coupled plasma optical emission spectrometry (ICP-OES) is usually used for the routine determination of aluminum content.[31,32] Also, aluminum content has been determined in beverages using graphite furnace atomic absorption spectrometry (GFAAS) and other similar and sensitive techniques. The high sensitivity, precision, and selectivity of GFAAS make it an excellent technique for determining Al.[33]

The non-destructive technique of X-ray fluorescence (XRF) does not require sample preparation to quantify aluminum content in trace levels.[34] Inductively coupled plasma (ICP) is commonly employed to analyze trace metals, including aluminum. Inductively coupled plasma atomic emission spectroscopy (ICP-AES) has been approved by the United States Environmental Protection Agency USEPA.[35,36] Flame atomic absorption spectrometry (FAAS) is a mature analytical method that is present in almost any analytical laboratory as a working horse for elemental metal determinations.[37] The most common method for investigating elements like aluminum is atomic absorption spectrometry (AAS). However, for very dilute solutions, chromatography,[38] cloud point extraction, solid-phase extraction,[39] and precipitation are some approaches that can be used to separate and pre-concentrate metal ions.[40-42] Graphite furnaces atomic absorption spectrometry (GFAAS) has evolved into an unrivaled method of ultra-trace analysis at a low cost over the last few decades. GFAAS has analytical advantages over FAAS and ICP-OES in that its limits of detection are about double amount higher, and it can analyze very small sample volumes.[43,44] Aluminum may leach into food from aluminum foil, cooking utensils, and containers, yet should not exceed the recommended daily limit for adults (less than 40 mg per kilogram of body mass).[45] Referring to the World Health Organization, aluminum can be found in 60% of people's bones, 25% of their lungs, 10% of their muscles, 3% of their liver, and 1% of their brains. Tea leaves, mushrooms, spinach, and radishes are more common than other foods to absorb and accumulate aluminum.[45,46]

Different factors are expected to affect aluminum leachings into food, such as the aluminum utensil used for cooking, the food acidity, the cooking temperature, the existence of salt, kind of spices, cooking duration, and the way of cooking. This study aimed to see how conventional cooking methods and their conditions affect aluminum leaching from aluminum foil into food.

EXPERIMENTALS

Instruments and Chemicals

- Atomic Absorption Spectroscopy (flameless), AA-7000, Shimadzu, Kyoto, Japan.
- All chemicals were of analytical grade.
- Aluminum foil (local market), China.

Preparation of Tartaric Acid Standard Solutions

A 50% stock solution of Tartaric Acid was prepared in a 100 mL volumetric flask by dissolving 50g of tartaric acid into distilled water and completed the volume to the mark. The other concentrations of (25, 15, 10, 5, 2, 1, 0.5, and 0.1%) were prepared in distilled water using the law of mitigation ($N_1 \times V_1 = N_2 \times V_2$).

Preparation of Acetic Acid Standard Solutions

The concentration of the stock solution of acetic acid was 99.7% w/w. The other concentrations of (25, 15, 10, 5, 2, 1, 0.5, and 0.1%) were prepared in distilled water using the law of mitigation ($N_1 \times V_1 = N_2 \times V_2$).

RESULTS AND DISCUSSION

To provide a scientific judgment on the aluminum content accumulated in our diet throughout cooking food wrapped with aluminum foil. We tried in this study to mimic the common major conditions that may affect releasing aluminum out of its foils during food preparations. Nevertheless, some extreme conditions have been examined to cover the effect for the examined factor independently fully.

Each factor has been studied thoroughly to inspect its influences on liberating more aluminum into the food wrapped with aluminum foil while cooking it.

Aluminum foil has been obtained from the local market (Thickness 0.045 mm, made in China). Then Aluminum sheets were shredded into small square pieces (~ 0.25 cm^2 each) for convenient and easier handling and comparison.

The Acidity of the Medium

The influence of acidity of the cooking medium was studied by dipping 0.1 g of the aluminum foil in pieces into 5 mL acidic solutions of different acidic percentages and hence different pH(s). Tartaric and acetic acids were employed to adjust the acidity as both are commonly used in kitchens for cooking, especially in eastern cuisines.

Samples of aluminum foils were left dipped in a set of 5ml acidic solutions of different concentration percentages of (0.1, 0.5, 1, 2, 5, 10, 15, 25, and 50) w/w% at a 12 ± 2 °C for 24 hours. Then the filtrates were numbered and collected into sample vials for pH measurement and later analyses by atomic absorption spectroscopy. The collected samples were digested by adding 5 drops of concentrated nitric acid to each sample vial.

The resultant measurements have exhibited an increase in the aluminum content with the increase of acid percentages. The effect of tartaric acid was much greater than the effect of acetic acid, especially for the percentages under 25%. While the acidification effect became identical for both acids, i.e., above 25%, both induced release of almost the same Al quantities (Figure 1).

However, the correlation was direct between aluminum content and the acidity of acetic acid as presented in Figure 2.

Similarly, the correlation of aluminum content as a function for the acidity of tartaric acid (pH) has exhibited an increase of aluminum concentration in the solution with the decrease in pH values, as shown in Figure 3.

Temperature Influence on Aluminum Degradation

Samples of aluminum foils were left dipped in a set of 5 mL acidic solutions of different concentration percentages of (0.1, 0.5, 1, 2, 5, 10, 15, 25, and 50) w/w% at different temperatures of 60 to 95°C for 2 hours. The filtrates were collected and numbered into sample vials for instant pH measurement and later analyses by atomic absorption spectroscopy to quantify the content of aluminum released. The collected samples were digested with 5 drops of concentrated nitric acid.

The acidified solutions have exhibited an increase in aluminum content with the increase in temperature. The effect of tartaric acid was greater than the effect of acetic acid, as demonstrated in Figure 4.

The effect of acetic acid was tested on the aluminum content at two different temperatures of (10 and 70°C) by dipping a (0.1 g) of aluminum foil pieces into 5 mL of the acid for 2 hours. Figure 5, showing the huge effect of the elevated temperature on the release of aluminum in the acidic solution of acetic acid.

In the same way, the effect of tartaric acid was tested on the aluminum content at two different temperatures of (10 and 70°C) by dipping a (0.1 g) of aluminum foil pieces into 5 mL of the acid for 2 hours. Figure 6 shows the elevated temperature's huge effect on the release of aluminum in the acidic solution.

It was obvious from Figures 5 and 6 that the temperature has a massive influence of releasing more aluminum from the foil to the acidic solutions and hence to the food wrapped with. This remark indicates that cooking food while wrapped with aluminum foil will have more aluminum content with increased cooking temperature.

Influence of Salt Presence on Aluminum Degradation

Samples of aluminum foils were left immersed in a set of 5 mL acidic solutions of different concentration percentages of (0.1, 0.5, 1, 2, 5, 10, 15, 25, and 50) w/w% at a temperature of 20°C. Different masses of sodium chloride salt (0.01, 0.011, 0.013, 0.015, 0.02, 0.022, 0.03, 0.04, and 0.05 g) were added to each sample mixture to inspect the effect of the added salt on degrading more aluminum into the solution.

After 24 hours the filtrates of each sample were collected and numbered into sample vials for instant pH measurement and later analyses by atomic absorption spectroscopy. After measuring the pH, the collected samples were digested by adding 5 drops of concentrated nitric acid.

The influence of acetic acid in the presence of sodium chloride in different concentrations tested as a function to the aluminum content degrades from the aluminum foils into the solution at the temperatures of 20°C after dipping a 0.1 g of the aluminum foil pieces into 5 mL of the acid for 24 hours. The obtained results of aluminum concentration in the solution in the presence of sodium chloride were compared to those before adding the salt (Figure 7).

The effect of tartaric acid with/without the presence of sodium chloride was tested as a function of the aluminum content degrades from the aluminum foils into the solution at 20°C,

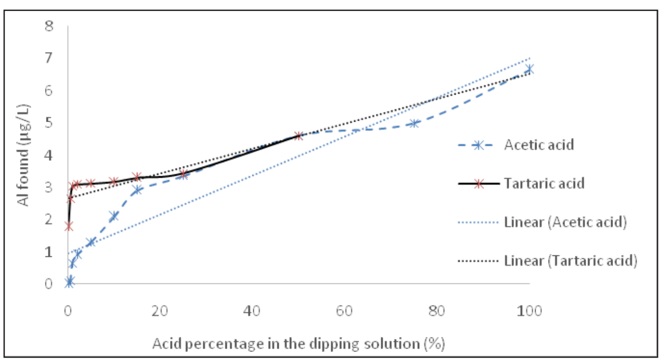

Figure 1: Aluminum content in solutions of different acid percentages (acetic and tartaric acids)

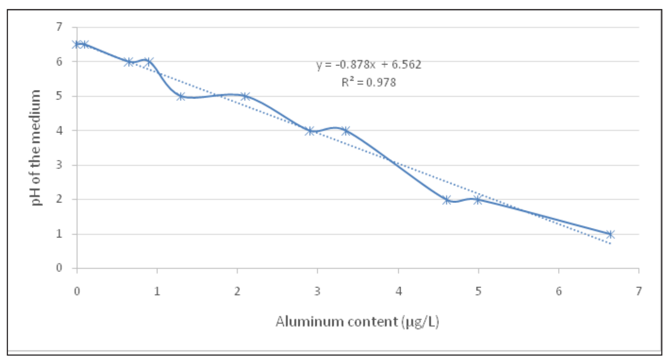

Figure 2: Direct correlation of aluminum content in the solution as a function for the concentration of the acetic acid.

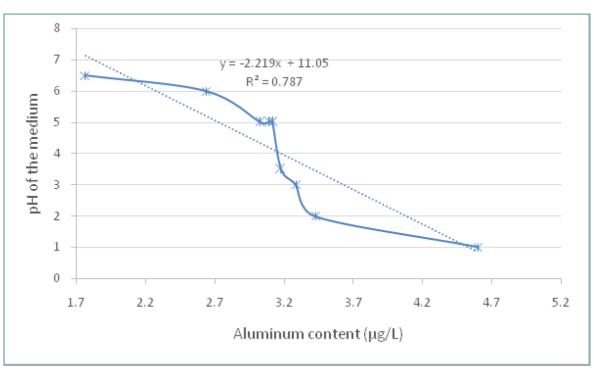

Figure 3: Raise of aluminum content in the solution as a function for the pH of tartaric acid solution

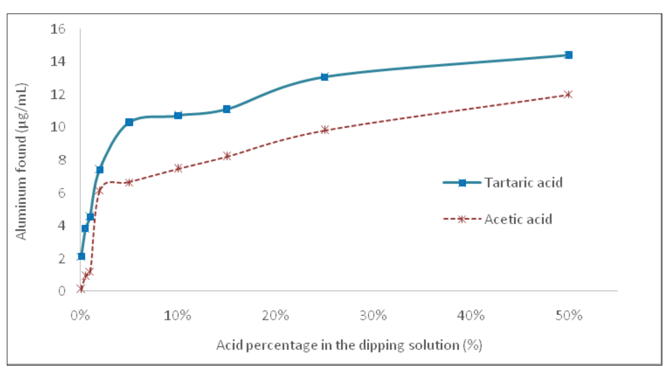

Figure 4: Effect of tartaric and acetic acids in different concentrations on the aluminum content at the temperature of 70°C

when a 0.1 g of the aluminum foil pieces were dipped in 5 mL acid for 24 hours (Figure 8).

It was clear from Figures 7 and 8 that the salt has an enormous effect of releasing more aluminum from the foil to the acidic solutions. This observation indicates that cooking food while wrapped with aluminum foil will release more aluminum with increased salt content.

The Effect of Oil Presence on Aluminum Degradation

Two beakers containing an exact mass of 0.5 g of aluminum foil pieces were placed in a water bath. The first was immersed in a 25 mL of cooking sunflower oil, while the second was immersed with 25 mL of distilled water. Aliquot of 5 mL from each mixture were taken each 15 minutes and left to cool down for a few minutes before adding 5 drops of nitric acid for digestion. The collected specimens were numbered into separate sample vials for later quantification of aluminum with atomic absorption spectroscopy. The results showed that the oil medium had released more aluminum than the aqueous within the same experimental conditions (Figure 9).

The Effect of Cooking Time on Aluminum Degradation

An exact mass of 0.5 g of aluminum foil pieces was placed separately into two beakers. Then a 25 mL of 1% tartaric acid was poured down in the first beaker while 25 mL of 10% tartaric acid was poured down in the other one. Both beakers were placed in a water bath adjusted to 70°C. Then different specimens of 5 mL volume were taken at different durations and the 2 hours overall time heating. The collected samples were left to cool down for a few minutes before adding 5 drops of nitric acid for complete digestion. Then the samples were numbered into separate sample vials for later analyses by atomic absorption spectroscopy to quantify the content of aluminum released in each solution of different compositions. The time duration affects the degradation of aluminum very clearly (Figure 10).

In the same way, an exact mass of 0.5 g of aluminum foil pieces was placed separately into two beakers. Then a 25 mL of 1% acetic acid was poured down in the first beaker while 25 mL of 10% acetic acid was poured down in the other one. Both beakers were placed in a water bath adjusted to 70°C. Then different specimens of 5 mL volume were taken at different durations along with the 2 hours overall time heating. The collected samples were left to cool down for a few minutes before adding 5 drops of nitric acid for complete digestion. Then the samples were numbered into separate sample vials for later analyses by atomic absorption spectroscopy. The time duration affects the degradation of aluminum very clearly (Figure 11).

However, generally tartaric acid increases the degradation of aluminum more than acetic acid.

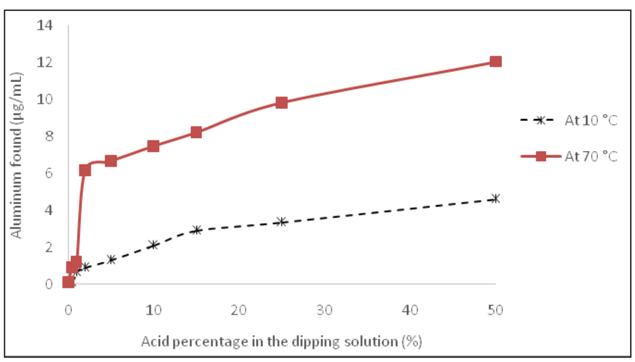

Figure 5: The effect of acetic acid on the aluminum content at two different temperatures of (10°C and 70°C)

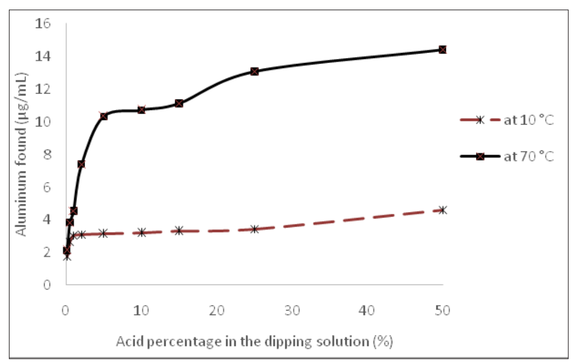

Figure 6: The effect of tartaric acid on the aluminum content at two different temperatures of (10°C and 70°C)

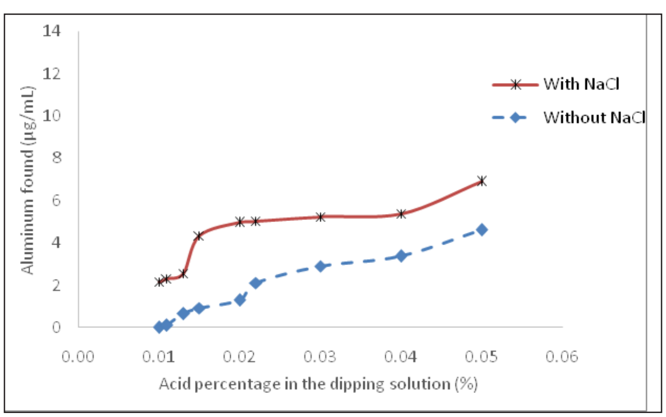

Figure 7: A comparison for the aluminum content leaked in an acidic solution of acetic acid before and after the addition of sodium chloride

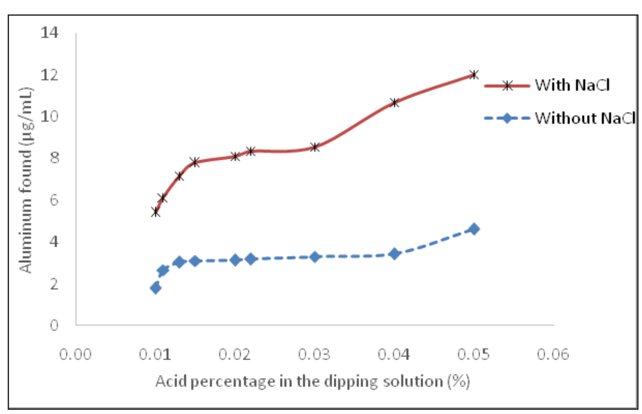

Figure 8: A comparison of the aluminum content leaked in an acidic solution of tartaric acid before and after the addition of sodium chloride

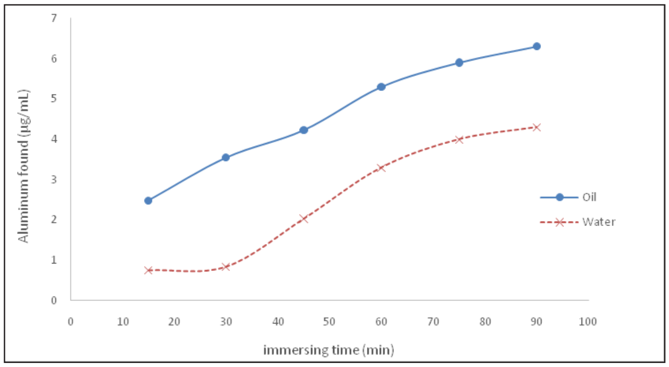

Figure 9: The effect of immersion medium at 100°C on the release of aluminum after the immersion of 0.5 g aluminum foil in pieces into 25 mL of oil and water respectively over a cooking period of 90 minutes

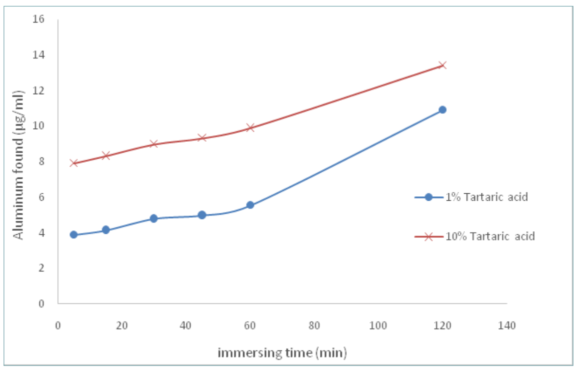

Figure 10: The effect of immersion time at 70°C on the release of aluminum in an acidified solution with tartaric acid over a cooking period of 120 minutes

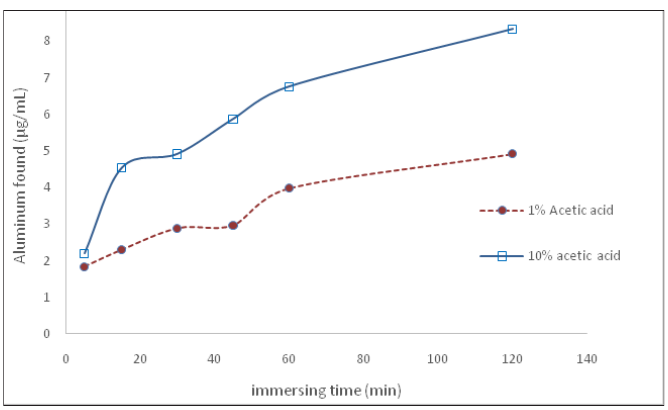

Figure 11: The effect of immersion time at 70°C on the release of aluminum in an acidified solution with acetic acid over a cooking period of 120 minutes

CONCLUSION

Different cooking conditions were examined to mimic the factors that may affect leaking aluminum into the foodstuff that cooked while wrapped with aluminum foil.

The study includes the pH of the cooking medium, two types of acids usually used in cuisines, namely acetic and tartaric acids, different cooking temperatures, the influence of the presence of sodium chloride salt, the effect of cooking oil as a cooking medium, and time duration of cooking on the aluminum content leaked into food cooked while wrapped with aluminum foil.

It has been found that almost all the suggested factors have increased aluminum leakage into the cooking medium. These findings advise us to avoid wrapping food with aluminum foil during cooking, especially in extreme conditions.

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