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Article

# Repurposing citrus peel waste and its positive effects on our health and communities

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## SUMMARY

**Every year, more than 30% of food products go to waste. This is approximately 1.3 billion tons of food, which is equivalent to 1.3 trillion U.S. dollars. While conventional solid waste treatments and fertilization of food waste are common, citrus fruit peels require secondary applications and advanced disposal management due to their low pH values and high antimicrobial characteristics. Since citrus fruits are well-known sources of vitamin C and antioxidants, we hypothesized that their peels also contain high amounts of vitamin C and antioxidants. In our study, five common citrus peels including grapefruit, lemon, lime, orange, and tangerine, were used to determine the amounts of vitamin C and total soluble antioxidants. Experimental results showed that lemon peels contain the highest vitamin C concentration (39.68 mg/g sample), closely followed by tangerine peels (37.23 mg/g sample). Lower vitamin C concentrations were extracted from the grapefruit, lime, and orange peels within a 3-hour reaction period with the average concentrations of 26.36 mg/g, 25.20 mg/g, and 24.53 mg/g sample, respectively. Despite containing a relatively low level of vitamin C, grapefruit peels demonstrated the highest antioxidant capacity (48.142 μmol Trolox/g peel sample), followed by orange, lemon, tangerine, and lime. Based on our results, if we were able to repurpose fruit peels and utilize them as a nutrient source, each U.S. individual would be able to meet the daily amount of the recommended vitamin C with 2-3 teaspoons of citrus peels reducing 4.8 pounds of the carbon dioxide ($CO_2$) equivalent annually at the same time.**

## INTRODUCTION

The food shortage and undernourishment of approximately 820 million people in the world has long been a global concern (1). Despite this alarming statistic, more than 30% of the food produced for human consumption, which is equivalent to nearly 1.3 billion tons, worth almost 1.3 trillion US dollars, is wasted each year (2). While most of the food waste happens at the processing stages, in industrialized countries, more than 60% of the food waste is produced at consumer levels (3). A previous report shows that the amount of food waste produced per capita in developed countries is about 15 times more than that in developing countries (4). Minimizing food waste through proper management and consumers' habits has the potential to transform the fate of the food waste toward beneficial applications, and the world hunger map would change significantly. In order for this to happen, consumers in industrialized nations need to be aware that even the small changes in our daily lives will dramatically reduce the unnourished population in the world.

Among the various types of food wastes, fruits and vegetables contribute the greatest amount (40–50% of total food waste). These values are exceptionally higher than those in other food groups, such as meat, fish, and dairy products (1). Most of the fruit and vegetable wastes decompose efficiently, and due to high biodegradable properties, composting them and dumping the wastes in landfill sites have been adopted in many countries (5). The conventional solid waste management, however, does not work efficiently for citrus peel waste due to their antimicrobial characteristics (6). As a result, citrus peel waste requires high-cost disposal management and causes potential environmental pollution. Citrus fruits, which account for about 20% of the overall fruit production in the world, have thick peels resulting in a very high (50–70%, w/w) waste production rate (7). According to Statista data, the total citrus fruit production in 2018 was 152.6 million tons, and about 55% of the productions consumed as fresh fruit generating up to 59 million tons of household waste (7, 8). While citrus peel waste from the industrial process can be utilized for the secondary applications or advanced disposal management, it is not practical to collect household citrus peel waste separately for further treatment. Therefore, the household citrus peel waste, in general, ends up with other home trash in landfill sites and threatens the environment by producing methane gas, which has a 25 times higher capacity as a greenhouse gas than carbon dioxide (9). With the low pH of the citrus fruit peels, discharging the citrus waste in the landfill may acidify the land resulting in the increased risk of toxic metal leachate. Various applications of citrus peel waste have been proposed by numerous groups and utilizing these peels as consumable nutritional resources is a particularly effective method for targeting zero waste discharge, even within individual households. Citrus fruits are a well-known source of vitamin C, which is one of the primary antioxidant sources along with polyphenols (10, 11). Therefore, we hypothesize the citrus peels will contain a significant amount of vitamin C that may be beneficial for intake. In this research, we analyzed the amounts of vitamin C and the total soluble antioxidants to provide data-based nutritional information of citrus peels, including grapefruit, orange, lemon, lime, and tangerine. Moreover, we examined the relationship between easily soluble vitamin C and the amount of total available antioxidants was studied. Considering the broad interests in human health and well-being, the primary objective of this work is to demonstrate how much an individual can reduce their carbon footprint upon utilizing citrus peel wastes, as well as raising awareness of their nutritional content through vitamin C.

## RESULTS

The available amounts of vitamin C and antioxidant capacity from grapefruit, lemon, lime, orange, and tangerine peels were investigated to provide nutritional information. The citrus fruits were obtained from a local market and the peel samples were thoroughly air-dried followed by grinding. Uniform particle size samples were obtained by sieving ground peels to determine soluble amounts of vitamin C and total antioxidants using spectrophotometric assays. The amount of vitamin C present in each sample was determined by measuring the absorbance at 510nm. With various prepared different concentrations of ascorbic acid solutions, the determined reference standard curve regression line is Y = 0.0029 X – 0.0387, where X and Y are absorbance and concentration, respectively (Figure 1).

The experimental data indicate that more vitamin C was extracted within 3 hours from the lemon peel (39.3 ± 0.7 mg/g), followed by tangerine peel (36.6 mg/g ± 0.5 mg/g), which were considerably higher values than those from the grapefruit, lime, and orange peels. There was no significant difference in the amount of extracted vitamin C observed in the grapefruit, lime, and orange peels with the 3-hour extraction average values of 26.3 ± 0.7 mg/g, 23.4 ± 1.4 mg/g, and 24.3 ± 0.2 mg/g, respectively (Figure 2).

Since there is no direct total antioxidant determination method available, in this research, Trolox was adopted as a reference antioxidant. Trolox Equivalent Antioxidant Capacity (TEAC) assay was adopted to determine the amount of total soluble amount of antioxidant from the same citrus fruit peels. The TEAC method uses the percent inhibition concept which quantifies the amount of antioxidant by measuring the degree of absorbance decrease at 735 nm in the presence of ABTS radicals (Table 1). The reference Trolox oxidant capacity slope was determined by plotting percent inhibition as a function of concentration (Figure 3). The TEAC value was calculated by comparing the slope of the sample to that for reference Trolox slope.

Despite the relatively low level of vitamin C, grapefruit peel had the highest amount of the antioxidant, followed by orange, lemon, tangerine, and lime (Figure 4). The data also shows that most of the available antioxidants can be extracted within 20 minutes. Considering the experimental results, it should be noted that the amount of dissolved vitamin C could not be used as an indicator to predict the antioxidant capacity from the citrus fruit peels (Figure 5).

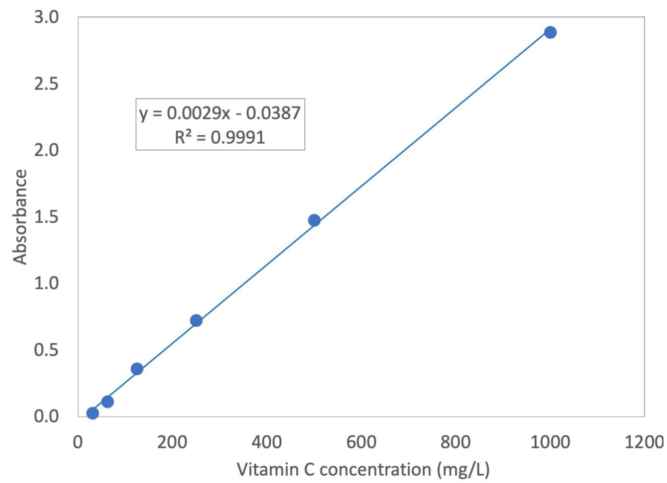


**Figure 1: Standard curve used for vitamin C determination.** Standard vitamin C solutions at 1,000 mg/L, 500 mg/L, 250 mg/L, 125 mg/L, 62.5 mg/L, and 32.25 mg/L were prepared using a serial dilution method. The experiment was duplicated, and the average value was used.

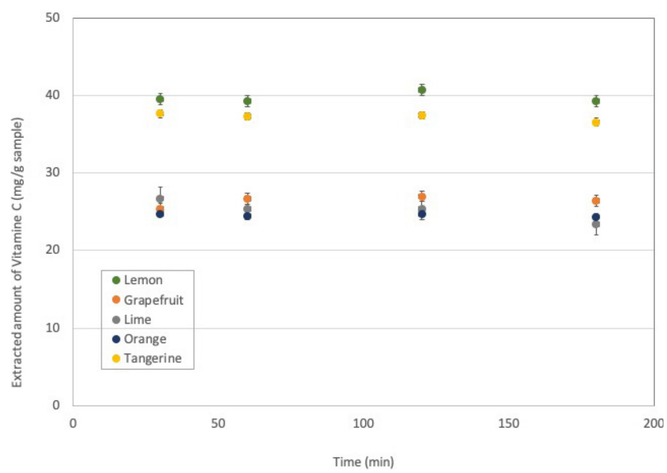


**Figure 2: Soluble amount of vitamin C from various citrus fruit peels as a function of reaction period.** The experiments were replicated four times and the error bars represent the standard deviations.

This study found that most of the water-extractable antioxidants and vitamin C could be extracted within 30 minutes of the reaction period. The highest amount of antioxidants was extracted from grapefruit peels, and more vitamin C was dissolved from the lemon peels. On the other hand, lime and orange peels showed the least available antioxidant and vitamin C, respectively. Besides, it was failed to observe the proportional relationship between the extracted vitamin C and antioxidant capacity.

## DISCUSSION

In order to identify potential secondary applications for the citrus fruit wastes in environmentally-friendly approaches, vitamin C and available soluble antioxidant amounts of five

| Trolox (μmol/L) | Absorbance | ∆ Absorbance from reference | % Inhibition |
|---|---|---|---|
| 250 | 0.738 | 0.188 | 20.3% |
| 125 | 0.824 | 0.102 | 11.0% |
| 62.5 | 0.877 | 0.049 | 5.2% |
| 31.25 | 0.902 | 0.024 | 2.5% |
| 0 | 0.926 | NA | NA |

**Table 1:** An example of % inhibition calculation.

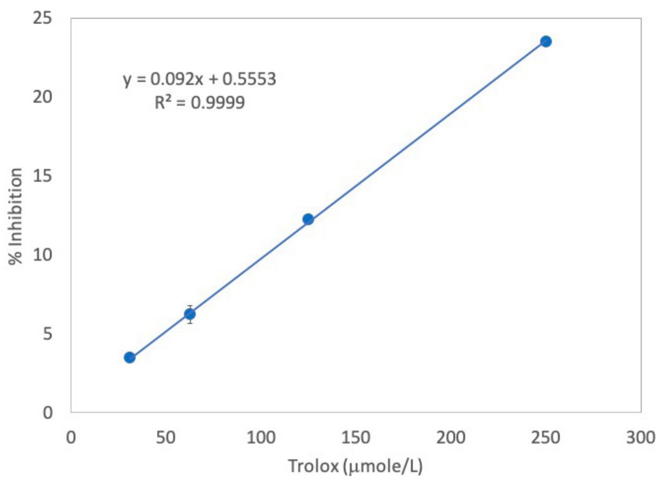


**Figure 3. Reference % inhibition graph of standard Trolox solution.** The reference Trolox concentrations were 250 μM, 125 μM, 62.5 μM, and 31.3 μM. The experiments were replicated five times and the error bars represent the standard deviations.

common citrus fruit peels — grapefruit, lemon, lime, orange, and tangerine — were analyzed. Reaction periods for this study were limited to up to 3 hours due to experimental and technical difficulties. As the reaction period was extended the solutions became cloudy, resulting in unstable spectroscopic measurements.

The average amounts of vitamin C from the lemon (39.7 ± 0.7 mg/g peel sample) and the tangerine (37.2 ± 0.5 mg/g peel sample) peels were higher than those from the other three peels when measured within a 3-hour reaction period (Figure 2). It should be noted that the extracted vitamin C amounts from grapefruit, lime, and tangerine peels were not significantly different from each other. The highest amount of antioxidants was extracted from the grapefruit peels (48.14 ± 0.05 μmol Trolox / g peel sample) followed by the lemon, orange, lime, and tangerine peels (Figure 4). While additional experiments are required, our studies showed that a higher antioxidant capacity corresponded with increased peel thickness.

Since vitamin C is one of the three major three categories for the natural antioxidants along with minerals and phytochemicals (12), the relationship between total available antioxidants and the extracted amount of vitamin C was observed. However, no proof of the proportional relationship between the amount of vitamin C and the total water-soluble antioxidant capacity was observed in this study (Figure 5).

We observed the five citrus fruit peels adopted in this study showed amounts of both vitamin C and antioxidants. Therefore, those citrus fruit peels could be possible alternative natural resources to provide daily nutritional requirements, thus reducing food wastes and greenhouse gases. The recommended intake of vitamin C for adult females and males, provided by the National Institute of Health (13), are 75 and 100 mg/day, respectively. The required amount can be easily achieved by taking 2–3 teaspoonfuls of dried citrus peels with a reasonable assumption of 2g per one spoonful. When the citrus fruit peels are consumed as nutritional resources, the secondary benefit of carbon footprint decrease, in addition to the household food waste reduction, will be achieved. In 2018, the average citrus fruit consumption per capita in the US was 24 pounds (14). Previous studies reported that the average waste production rate of citrus fruit is 60%, and the amount of carbon footprint produced by citrus fruit waste per capita is the $CO_2$ equivalent rate of 0.20 kg of $CO_2$ / kg per orange harvested (7, 15). The information concludes that each person in the US produces 4.8 pounds of carbon dioxide equivalent every year by consuming citrus fruits.

In summary, utilizing citrus fruit peels as an alternative for vitamin C can yield tremendous benefits by lowering total food waste generated; for the standard U.S. household of four, this can be up to 57.6 pounds of citrus-related waste annually. This could help alleviate the costs required to maintain waste transportation and landfill. Other environmental benefits include a reduction in greenhouse gases produced (about 19.2 pounds of carbon dioxide equivalent), which is nearly the same as saving 1 gallon of gasoline (16). Having households adopt these simple and eco-friendly practices is one of the first steps towards paving the way forward into a cleaner and healthier environment.

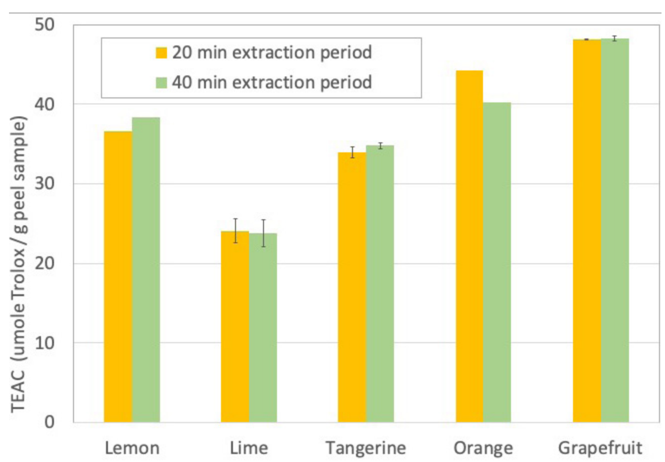


**Figure 4. Total water-soluble antioxidant capacity of various citrus fruit peels.** Experiments with lime, tangerine, and grapefruit were duplicated and the error bars represent the standard deviation.

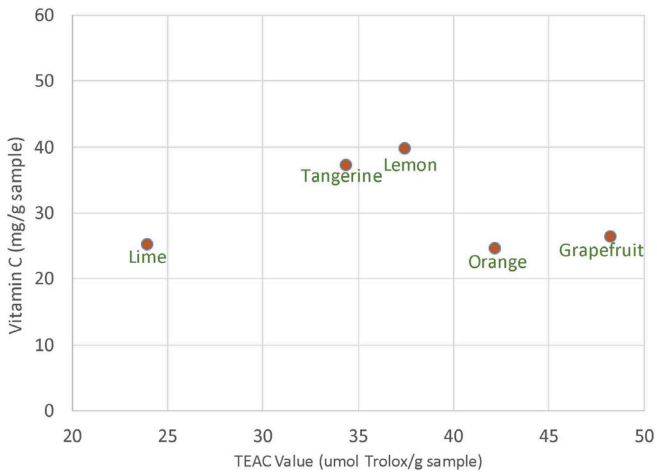


**Figure 5: The relationship between extracted vitamin C in mg-vitamin C/g-sample and soluble antioxidant amount in μmole-Trolox/g-sample from various citrus fruit peels.**

## MATERIALS AND METHODS

Typical organic citrus fruit samples including grapefruit, lime, lemon, orange, and tangerine, were purchased from a local market. The peels were collected and air-dried for two weeks to reduce the peel samples' water content. The dried samples were ground using a commercial coffee grinder followed by an additional one-week air dry. For this research, peel particle size was between 0.500 mm and 0.710 mm. To obtain the uniform particle size, the ground sample was sieved using US standard sieve number 25 (0.710 mm), and sieve number 35 (0.500 mm).

0.25 grams of peel sample was mixed with 25mL of water in a 50 mL centrifuge tube for the antioxidant experiment. For the vitamin C experiments, 0.2g of the peel sample was added into a centrifuge tube including 10 mL of water resulting in the mass to water ratios of 20 g/L and 10 g/L for vitamin C and antioxidant experiments, respectively. The tube was fixed to a rotary mixer and run during the experimental period. Approximately 1mL of the solution was taken as a function of time followed by a filtration using a qualitative filter paper (Fisher P5). The filtrate was used for vitamin C and the total antioxidant capacity analysis.

To determine the amount of vitamin C extracted from the samples, a spectrophotometric method proposed by Besada (17) was used. The color developmental 1,10-phenanthroline-ferric ion indicator was prepared in an amber bottle and stored in a refrigerator (4˚C). 0.2 mL of the filtered sample was added to a test tube which included 1mL of the indicator and 0.5 mL of water. The absorbance of the prepared solution was determined at 510 nm after 10 minutes of the reaction period. Fresh 1,000 mg/L L-ascorbic acid stock solution was made and diluted it to prepare various standard solutions to build the standard curve.

The Trolox Equivalent Antioxidant Capacity (TEAC) assay (18) was used in this research to determine the total amount of water-soluble antioxidant capacity. The initial 2,2-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) radical (ABTS•) solution was prepared by mixing same volume of 14 mM ABTS solution and 4.9 mM potassium persulfate solution. The freshly-prepared ABTS• solution was stored in an amber bottle and aged for at least 10 hours before adopting for the experiments. The aged ABTS• solution was diluted to adjust the initial absorbance at 735 nm between 0.8 and 1.2. To determine the change of absorbance (Δ absorbance), 0.1 mL of filtrate was mixed with 2.9 mL of the diluted ABTS• solution and the absorbance was determined after 6 minutes of reaction period. The disappearance of the ABTS• can be expressed as % inhibition, as shown below.

$$\%\,inhibition = \left(\frac{\Delta\,Absorbance}{Absorbance\ of\ reference}\right)\times 100$$
$$= \left(\frac{Absorbance\ of\ reference - Absorbance\ of\ test}{Absorbance\ of\ reference}\right)\times 100$$

With the collected data, % inhibitions at various concentrations were calculated (Table 1) and a plot of % inhibition (Y-axis) vs. sample concentration (X-axis) was built to determine the slope of the trendline (Figure 3). The antioxidant capacity was expressed as TEAC values which were determined by comparing the slopes of the sample and Trolox % inhibition graphs. The unit for the TEAC values for this research can be expressed as:

$$TEAC\ Values\ unit = \frac{unit\ for\ the\ slope\ of\ Sample}{unit\ for\ the\ slope\ of\ Trolox} = \frac{\left[\frac{\%\,inhibition}{g\ of\ Sample\,/\,L}\right]}{\left[\frac{\%\,inhibtion}{\mu mole\ of\ Trolox\,/\,L}\right]}$$
$$= \left[\frac{\mu mole\ of\ Trolox}{g\ of\ sample}\right]$$

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