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Selected nutrient analyses of fresh, fresh-stored, and frozen fruits and vegetables

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ABSTRACT

This two-year study compared the status of targeted nutrients in selected fresh and frozen fruits and vegetables. In addition, a novel third category was examined—a "fresh-stored" categorization intended to mimic typical consumer storage patterns of produce following purchase (five days of refrigeration). Broccoli, cauliflower, corn, green beans, green peas, spinach, blueberries, and strawberries of all three categories of freshness were analyzed for their concentrations of L-ascorbic acid (vitamin C), *trans*-β-carotene (provitamin A), and total folate. Analyses were performed in triplicate on representative samples using standardized analytical methods and included a quality control plan for each nutrient. In the majority of comparisons between nutrients within the categories of fresh, frozen, and "fresh-stored", the findings showed no significant differences in assessed vitamin contents. In the cases of significant differences, frozen produce outperformed "fresh-stored" more frequently than "fresh-stored" outperformed frozen. When considering the refrigerated storage to which consumers may expose their fresh produce prior to consumption, the findings of this study do not support the common belief of consumers that fresh food has significantly greater nutritional value than its frozen counterpart.

1. Introduction

There is strong evidence that public health could be improved by increased consumption rates of fruits and vegetables (CDC, 2013). Many fruits and vegetables are important sources of nutrients that are consumed at inadequate levels in the U.S., including vitamin A, vitamin C, calcium, magnesium, and others (Agarwal et al., 2015). Fruits and vegetables also frequently contain high concentrations of bioactive compounds, and have been shown to exhibit high antioxidant potentials (Liu, 2013). Furthermore, when prepared without added fats or sugars, fruits and vegetables are generally relatively low in calories, high in dietary fiber, and beneficial to satiety (Fulton et al., 2016). The consumption of fruits and vegetables has been shown to aid in healthy weight maintenance, and associate with a reduced risk of multiple chronic diseases (CDC, 2013).

Despite these points, a 2013 Center for Disease Control (CDC) reports that 33% of American adults consume less than one serving of fruits and vegetables a day. Governmental and public health agencies continue to apply ongoing efforts to improve consumption rates of fruits and vegetables for the benefit of public health. For example, the 2015–2020 USDA Dietary Guidelines for Americans advise individuals to increase their intake of fruits and vegetables to help control total caloric intake and manage body weight (U.S. Department of Health and Human Services and U.S. Department of Agriculture, 2015; U.S. Department of Agriculture, Agricultural Research Service, 2015). The formal suggestion of MyPlate, the revised USDA Food Pyramid, suggests that half of the plate should be comprised of nutrient-dense foods such as fruits and vegetables. These guidelines also highlight the importance of variety, which is necessary to give the human body the large array of vitamins, minerals and macronutrients it needs.

The disparity between dietary recommendations and noted large-scale dietary patterns is a source of ongoing investigation, and it is apparent the causes are multi-faceted and diverse (Deliens et al., 2014; Haynes-Maslow et al., 2013; Stok et al., 2014). One

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documented explanation for inadequate fruit and vegetable consumption is a lack of high quality fresh produce choices for consumers, which may frequently be limited by spoilage and losses during transportation and/or storage (Buzby et al., 2014). This is especially the case during winter months, when quality is generally diminished and cost is often higher. Even when produce remains sufficiently unspoiled so as to merit purchase and consumption, there may be more minor degradations (e.g. enzymatic degradations, cellular respiration and oxidation) that can negatively affect their nutritional benefit (Bouzari et al., 2015).

Prior studies investigating fresh produce have determined fresh produce is frequently picked before peak ripeness, packaged, stored, transported, and then stored again (Blackburn and Scudder, 2009). It has been established in prior investigations that post-harvest exposure to periods of storage and transportation at temperatures above freezing can negatively affect nutrient quality, specifically nutrients with antioxidant potential (Villa-Rodriguez et al., 2015). Nutrients from produce will also be affected by genetic factors, climatic factors, and has been shown to be negatively associated with periods of exposure to light and/or oxygen (Alvarez-Suarez et al., 2014).

In efforts to lessen spoilage and degradation, a number of storage and production techniques have been investigated and introduced for produce in recent years. Prominent among these has been the implementation of modified atmospheres, which has been demonstrated to reduce degradation during storage (Oliveira et al., 2015). However, benefits of modified atmospheres discontinue once the package has been opened at the home of the consumer. Other recent innovations have included investigations into the use of edible oil coatings, ethylene absorbers, and the incorporation of anti-microbial agents into packaging materials (Brandwein et al., 2016; Patrignani et al., 2015; Sahu et al., 2016).

In principle, the freezing of fruits and vegetables could serve to provide a highly beneficial mitigation of the problems of spoilage and/or degradation, and provide consumers increased access to nutritious fruits and vegetables. This outcome has, of course, occurred for many consumers, but evidence shows that the scope of its reach continues to be limited by a persistent public perception that the preservation or processing of fruits and vegetables substantially diminishes nutritional quality (Ares et al., 2014). It has been shown that these perceptions continue to influence the choices of consumers (Haynes-Maslow et al., 2013). The validity of the continuing perception of frozen produce being of relatively lesser nutritional quality is a point worthy of investigation, for if it is in fact not accurate, its persistence may play a negative role in public health.

When comparing the nutritional qualities of fruits and vegetables from different processes (specifically the comparison of fresh produce and frozen produce), a point of relatively infrequent examination is that fresh produce may often remain in the consumer's home for a number of days prior to consumption. According to the research of the Food Marketing Institute, the average number of trips to the supermarket in the United States was 1.5 times per week in 2015 (Food Marketing Institute, 2015). This suggests the average consumer stores purchased food in their home for a period of time of nearly five days prior to a return to the supermarket. This in-house storage may very plausibly contribute to losses of nutritional quality, therefore making the comparison of fresh and frozen produce more complicated than is commonly considered in studies.To the knowledge of the authors, the nutritional quality of fresh produce specifically after a period of refrigerated storage that is intended to replicate consumer storage patterns has not received prior investigation.

The aim of this study was to determine and compare the status of targeted nutrients in selected fresh, frozen, and "fresh-stored" fruits and vegetables. The "fresh-stored" storage parameter (five days of refrigerated storage) was developed by the researchers for the purpose of approximating typical consumer storage patterns (designed with reference to the data of Food Marketing Institute 2015). The study assessed L-ascorbic acid (vitamin C), *trans*-β-carotene (provitamin A), and total folate concentrations within blueberries, strawberries, broccoli, cauliflower, corn, green beans, spinach, and green peas. The decision of what fruits and vegetables to investigate was predetermined by the Frozen Food Foundation (FFF), the funding agency for this study. Their pick of what to examine was based on the findings reported in a white paper commissioned by the FFF. This document, entitled 'Nutritional comparison of frozen and non-frozen fruits and vegetables: Literature review' was prepared by scientists from the Food Processing Center at the University of Nebraska-Lincoln (Kyureghian et al., 2010). So, the choice of produce and nutrients to be analyzed was not random. The choices were based on U.S. consumption patterns and nutrients (i.e., vitamins C, A, folate, and minerals) stipulated by the FFF as being important

2. Materials and methods

2.1. Materials

Produce, both fresh and private-label frozen, was purchased from supermarkets within a 40 km radius of Athens, GA, USA (i.e., Walmart, Sam's Club, Kroger, Publix, Piggly-Wiggly, Ingles, and Bells). The produce included six vegetables and two fruits, namely broccoli (*Brassica oleracea* var. *italica*), cauliflower (*Brassica oleracea* var. *botrytis*), sweet corn (*Zea mays* L. convar. *saccharata* Körn), green beans (*Phaseolus vulgaris* L.), green peas (*Pisum sativum* L.), spinach (*Spinacia oleracea* L.), blueberries (*Vaccinium corymbosum* L.), and strawberries (*Fragaria* × *ananassa*).

ACS-grade *meta*-phosphoric acid pellets, USP-grade L-ascorbic acid (purity, 99.9%), BD Difco™ *Lactobacilli* broth, *Lactobacilli* agar, folic acid casei medium powder, and Pronase® protease (Cat No. 537002-50KU) were purchased from VWR International (Suwanee, GA, USA). ACS-grade glacial acetic acid, hydrochloric acid, sodium hydroxide, 95% (*v*/*v*) ethanol, and toluene as well as 2,6-dichloroindophenol sodium salt hydrate (purity, 98+%), HPLC-grade methanol, HPLC-grade methyl *tert*-butyl ether (MTBE), and pyrogallol were obtained from the Fisher Scientific Company (Suwanee, GA, USA). *trans*-β-Carotene (type I, synthetic, ≥93%), 1,4-α-D-glucan glucanohydrolase (i.e., α-amylase) from *Aspergillus oryzae* (Cat. No. 10065-50G) and USP-grade folic acid (purity, 99.9%) were procured from the Sigma-Aldrich Chemical Company (St. Louis, MO, USA). Unpurified, but acetone-washed, conjugase was isolated from freshly-slaughtered chicken pancreata acquired from the University of Georgia's Department of Poultry Science (Athens, GA, USA).

Certified reference materials (CRMs) from the European Commission Joint Research Center, Institute for Reference Materials and Measurements, were purchased from the Resource Technology Corporation (Laramie, WY, USA); these included BCR®–431 (Brussels sprouts powder with a certified value of 4.83 ± 0.24 g/kg for vitamin C) and BCR®–485 (mixed vegetables with certified values of 23.7 ± 1.5 mg/kg for *trans*-β-carotene and 3.15 ± 0.28 mg/kg for total folate). Gold Medal, enriched, AP flour – an in-house quality control (QC) marker for the folate assay – was purchased from Kroger (Athens, GA, USA).

2.2. Sample acquisition, storage and preparation

The analyses of this study were performed over the span of two years in six distinct time frames: (1) Summer to Fall Year 1, (2) Fall to Winter Year 1, (3) Winter to Spring Year 1, (4) Summer to Fall Year 2, (5) Fall to Winter Year 2, and (6) Winter to Spring Year 2. The