



Review Article

Meta-Analysis of Studies on Vitamin C Contents of Fresh and Processed Fruits and Vegetables

Gayaneh Kyureghian^{1*} and Rolando Flores²

Abstract

The effects of processing and pre- and post-harvest handling on nutritional contents, vitamin C in particular, of fruits and vegetables have been extensively researched and well documented. While fresh produce is not subjected to nutrition deterioration inevitable in chemical and thermal processing, nutrient reduction due to suboptimal storage conditions and time can be substantial. Processed produce, on the other hand, incurs minimal post-harvest damage, but is subjected to damage due to chemical and thermal processing. The extent and prevalence of the resulting deterioration in vitamin C in selected fruits and vegetables have been demonstrated by many studies. While limited attempts were made to reconcile the literature findings for selected fruits and vegetables, none was made to generalize the separate findings to make inference regarding the entire category of fruits and vegetables. The objective of this review is to assimilate the literature findings to derive statistical inference concerning the comparison of vitamin C contents in fresh and non-fresh fruits and vegetables. The relevant literature was reviewed to identify publications that assess the vitamin C contents of all forms of fresh and non-fresh fruits and vegetables. Meta-analytic techniques were used to assimilate the findings and statistical analysis was conducted using mixed effects model. The results show no statistical difference between the vitamin C contents of fresh and processed fruits and vegetables. No statistically significant difference is detected, when repeating the analysis for separate processing types—frozen, canned, and juiced. The results are robust to different specifications of the statistical model.

Keywords: Meta-Analysis; Mixed effects; Fruits; Vegetables; Vitamin C; Ascorbic acid

Introduction

The Dietary Guidelines for Americans, 2010, highlights the alarmingly low consumption of some micronutrients, vitamin C among others, and recommends a diet shift that emphasizes consumption of nutrient-dense foods, fruits and vegetables in particular, as a rich source of nutrients typically under-consumed in the U.S. [1]. Despite these efforts, only 42% and less than 60% of Americans meet the recommendations for fruit and vegetable consumption, respectively [1]. Since more than 90% of vitamin C intake in human diets comes from fruits and vegetables [2], it is not unexpected that vitamin C consumption is far from the recommended levels as well. According to dietary intake data from the National Health and Nutrition Examination Survey (NHANES), National Center for Health Statistics and Centers for Disease Control

and Prevention, the proportion of the population under-consuming vitamin C is on the rise for all age/gender groups, with the sole exception of females under the age of one. Figure 1 depicts this trend.

Factors such as price and retail food availability are likely to affect consumption decisions. Approximately, 51% of all fruits and 46% of vegetables are consumed fresh [3]. According to Economic Research Service (ERS), USDA, the prices for processed most frequently purchased fruits—apples, grapes and oranges are on an average 39%, 76% and 42% of the fresh prices, respectively. The prices for processed most frequently purchased vegetables—potatoes, tomatoes, and corn are on an average 73%, 15% and 29% of the fresh prices, respectively¹. Additionally, the longer shelf life of processed produce alleviates the fruit and vegetable availability problems in remote, underserved areas. These two conditions combined, make processed² produce a more affordable and readily available substitute to fresh produce, and therefore may be used to increase fruit and vegetable consumption and help meet the dietary recommendations for vitamin C intake, provided that processed produce is an equivalent source of vitamin C. This study seeks to test this hypothesis.

As mentioned above, vitamin C is most sensitive to pre- and post-harvest handling conditions. Levels of vitamin C are determined by a combination of factors, such as the particular cultivar type, climatic and soil conditions, maturity at harvest, storage duration and conditions, type and duration of chemical and thermal processing, physical damage, etc. [2]. In the case of processed produce, while vitamin C is reduced due to thermal and chemical treatments, the loss of vitamin C due to premature harvesting and postharvest adverse conditions is minimized. In the case of the fresh

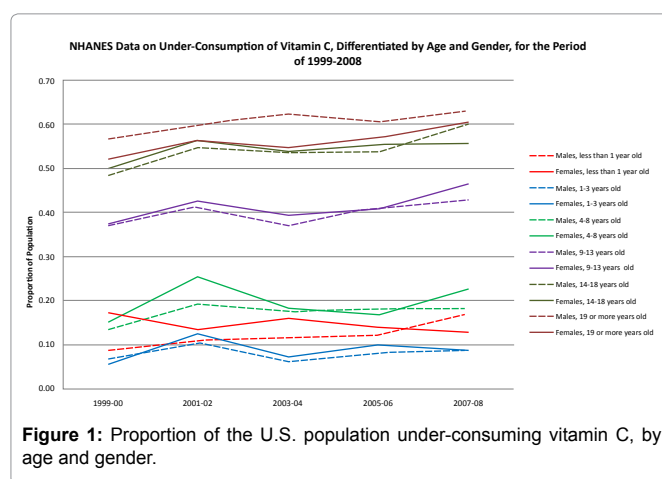


Figure 1: Proportion of the U.S. population under-consuming vitamin C, by age and gender.

*Corresponding author: Dr. Gayaneh Kyureghian, Department of Food Science and Technology, The Food Processing Center, University of Nebraska-Lincoln, USA, Tel: (402) 479-2064; Fax: (402) 472-8593; E-mail: GKkyureghian2@unl.edu

Received: June 16, 2012 Accepted: October 19, 2012 Published: October 22, 2012

¹Corresponding tables from Yearbooks, ERS, USDA, and "Price Spreads from Farm to Consumer: At-Home Foods by Commodity Groups", ERS, USDA, were used to derive the retail-level prices from farm-level prices. The spread developed by ERS, USDA are based on the shelf prices for selected products from the Bureau of Labor Statistics, United States Department of Labor, which may explain the differences in findings by Stewart et al. (2011) and the authors of this manuscript.

²Throughout this study, all the types of non-fresh produce are referred to as "processed".

produce, the situation is reversed—while there is no damage due to the thermal or chemical processes, excessive storage time before it reaches the final consumer, premature harvesting and postharvest damage may cause significant losses in vitamin C [4]. According to the National Sustainable Agriculture Information Service, fruits and vegetables travel thousands of miles before reaching the market. For example, grapes travel 2,143 miles, broccoli travels 2,095 miles, and apples travel 1,555 miles before reaching the Chicago market [5]. Considering the pros and cons for vitamin C retention in fresh and processed fruits and vegetables, the vitamin C equivalency between fresh and processed fruits and vegetables is an empirical matter, and therefore, is a testable one.

The objective of this study is to assimilate the literature findings on the contents of vitamin C in fruits and vegetables, to compile a comprehensive database big enough to enable regression analysis. In the previous literature, limited efforts have been made to accomplish database creation [6-8], but to our knowledge, no efforts were made to draw regression inference.

The literature findings are synthesized using meta-analytic techniques to allow comparison between vitamin C contents of fresh vs. processed produce. The hypothesis tested is that there is no statistically significant difference in vitamin C contents in fresh and processed produce. Failure to reject this hypothesis would provide a foundation of diet augmentation to increase vitamin C intakes, via increasing processed fruit and vegetable consumption, without major budgetary intervention. Statistical techniques appropriate for analyzing hierarchical data resulting from the data assimilation from heterogeneous sources, such as mixed effects models were used.

Data

Literature review

This review utilizes a subsample of the studies from a literature review of nutritional composition of frozen and non-frozen fruits and vegetables that provide quantitative information on vitamin C contents of produce [8]. The choice of the subsample is based on the availability of minimal information necessary to conduct a meta-analysis. A complementary literature search using an alternative search technique—a keyword search, was performed to identify more publications that contain quantitative information on the vitamin C content of fruits and vegetables. The databases searched were the Web of Science and Pub Med. Separate periodicals frequently encountered in the previous search were individually searched using the same keywords.

The final database consists of articles from the Kyureghian et al. [8] review, and articles found through keyword search, and the bibliographic references of the located articles. The inclusion criteria for the articles included:

- (i) Original articles that provide quantitative information about the levels of vitamin C in fruits or vegetables. Articles that provide percentages or retention rates, but also provide initial level information, such that the levels can be deterministically recovered were retained;
- (ii) The type of document is identified as original articles published in peer reviewed journals. Therefore, abstracts, conference proceedings, unpublished working papers, reviews, books, government reports, etc. were not retained.

The search identified 47 studies fulfilling the entry criteria [9-55], spanning from 1941 to August, 2010, published in 15 journals. Combined, they provided 1061 observations. The studies are listed by the first authors name and the year of publication, in table A1, Appendix A. A full reference list of the included articles follows.

Data extraction

In the included studies, fruits and vegetables typically follow a path from harvest to pretreatment to processing. The vitamin C extraction is performed from either cooked or uncooked (raw) form of the fresh and/or processed products. For each step of this process, all the possible variable values were recorded to construct, as complete a database, as possible. Following this design, the database contains one observation per measured vitamin C quantity per paper. For example, if a study has an objective to measure the vitamin C contents of 2 broccoli and 3 green bean varieties in fresh and frozen types, stored for 4 different time intervals each and extracted by 2 methods, then this study would have contributed $80 (2 \times 2 \times 4 \times 2 = 32)$ for broccoli and $48 (3 \times 2 \times 4 \times 2 = 48)$ for green beans) observations to the database.

The choice of variables of interest for the analysis was largely guided by the literature. What follows is the list and description of variables recorded from the included studies.

The common or Latin *name* and *variety* of the products were recorded, to be able to identify the product as accurately as possible. There were 56 types (called “*Product*”, henceforth) of fruits and vegetables used in the studies. In addition to grouping observations by *Product*, the fruits and vegetables were also classified in *Groups* of products, defined by their functionality traits or other characteristics [56]. The classification of fruits and vegetables is not a simple task, nor is it unique. Several classification schemes are possible, based on the composition of the fruits and vegetables, national consumption patterns, botanic family, color, and edible parts of plants. Five classification groups are defined & followed herein: *MyPyramid*, *Color*, *Total Antioxidant Capacity (TAC)*, *Part of Plant*, and *Cluster* [56]. A sixth group defined by *MyPlate* was added as well. *MyPyramid* and *MyPlate* group includes the fruits and vegetables based on the macronutrients, nine vitamins and eight minerals. *Color* reflects the pigments in the tissue that are identifiable with some components, e.g. beta-carotene is deep orange. *TAC* describes the number of antioxidants contained in the plant. The classification by edible part (*Part of Plant*) groups fruits and vegetables by the part of the plant that is used as food. The *Cluster* method classifies fruits and vegetables by using mathematical models of principal components to cluster fruits and vegetables [56].

Year represents the calendar year of the analysis. If not mentioned explicitly in the study, the research publication date is used instead. *Storage* variable reflects the number of days between obtaining the produce and vitamin C extraction. Where a range of values was given, averages were used.

A binary variable –*Cooked* was constructed to account for the preparedness condition of the produce that equals to unity, if the *Product* is cooked, and zero otherwise. The processing type of the *Product*: *Fresh*, *Frozen*, *Canned* or *Juiced* was part of the objectives and was therefore, uniformly reported in the studies and duly recorded.

As agricultural production became increasingly specialized and regionally specific, food travels non-trivial distances (commonly referred to as food miles) before it reaches the final consumers in retail

outlets. Therefore, the notion of “fresh” may have evolved since 1941–the year of the first analysis included in this review. In other words, what earlier studies referred to as “fresh” may not be the “fresh” the more recent papers refer to, as far as vitamin C is concerned. To account for this effect, a binary variable *Supercenter* was constructed that equals to unity, if the Product was obtained from a retail location, and zero otherwise.

In the sample of studies, the *vitamin C* was measured in milligrams per hundred gram units, almost uniformly. In isolated cases where the measurement units were different, the appropriate affine transformations were made to ascertain the uniformity in the measurement unit.

Other possible covariates such as the region; pretreatment type, duration and temperature; processing duration and temperature; shipping/storage conditions (temperature, humidity and light exposure, etc.) and time; cooking time and temperature; and vitamin C extraction method were not included in the estimation due to a high proportion of missingness, and/or other reasons. The summary statistics of the variables are presented in [table 1](#).

As the results in [table 1](#) indicate, the average amount of vitamin C detected in all types of produce by the studies in the sample was approximately 291 mg/100 g. Of the entire sample, 38.55% of produce was not fresh. Within this processed category, 30.63% was frozen, 3.30% was canned and the remaining–4.62% was in the form of juice. Approximately, 45.33% of the produce was obtained from a retail location, with the rest obtained either from the experimental lots of their corresponding universities, or from roadside farm sales. The samples were stored on average 47.5 days before vitamin C extraction, with an average number of determinations of less than 5. Of the whole sample, 18.57% of the produce was cooked before extraction; the rest was analyzed in its original form–fresh, frozen, canned or juiced.

Data measurement issues

Throughout the literature, *vitamin C* was measured either in dry or fresh/wet weight basis. Considering the fact that all fruits and vegetables in the sample consisted of 65% (lima beans) to 96% (iceberg lettuce) water, it is important to express vitamin C contents on a common weight basis. The conversion for a particular product *i*, is performed by the formula below:

$$Vitamin\ C_{DryWeight,i} = \frac{100}{100 - Moisture_i} \times Vitamin\ C_{FreshWeight,i}$$

This posed a problem as many studies that reported vitamin C contents on fresh weight basis did not necessarily report the *moisture*

levels as well. To deal with this problem, the cold deck imputation method was used to fill in the missing moisture values for the corresponding *Products* reported in the Nutrient Database, NDB (USDA National Nutrient Database for Standard Reference Release 23). To ascertain the validity of this imputation, the objectives and the methods USDA used to compile the NDB were studied. Despite the obvious differences in the objectives of the studies and the NDB, the NDB moisture levels may be reasonable proxies to the moisture levels reported in the literature. In order to establish the validity of these proxies, the NDB moisture levels were regressed against the moisture levels reported by the articles. The rejection of H_0 : intercept=0 and slope=1 (F value=1.37, p-value=0.2569) was failed, thereby validating the NDB moisture values as proxies.

Data reporting issues

As the extraction process is subject to many measurement errors, *vitamin C* contents are typically measured multiple times. The mean, numbers of measurements and standard deviations are typically reported. The standard deviations, however, had a missingness rate of approximately 47% in the sample. As a measure of accuracy of the different realizations of *vitamin C*, the standard deviations are used in creating weights in the data assimilation and the subsequent meta-analysis. Addressing missingness is always a challenge, especially when the proportion of missingness is relatively high, as in this case. Discarding observations with missing standard deviations is not an option, as it drastically reduces the sample size, and limits the power for the estimation of variance components in the analysis.

The multiple imputation (MI) method is used to fill in the missing standard deviations. MI methods generate multiple values for each missing datum, which are subsequently combined to form the parameters of interest [57]. Given the continuous nature of the variable with missing values and the pattern of missingness (monotone), the Propensity Score method of MI was chosen. A graphic analysis of the imputed and the observed standard deviations was performed to depict the goodness or validity of imputation. The purpose of this validation is to ensure that by filling in the missing values, the original distribution of the standard deviations was not altered in any way that would result in biased parameter estimates in the consequent estimations. [Figure 2](#) shows reasonably close non-parametrically smoothed (kernel) densities of the observed and imputed standard deviations (the three highest observations of the standard deviation are dropped for improving the visual representation only). The summary statistics reveal that the imputed standard deviations have tighter distribution, with a narrower distance between the mean and median, compared to the distribution of the observed standard

Table 1: Variables names, descriptions and summary statistics.

Variable	Description	Mean	Minimum	Maximum	Std Dev
Vit_C	Vitamin C in mg/100g	291.0452	1.6260	1824.8800	302.3695
InVit_C	Natural logarithm of vitamin C	5.0832	0.4861	7.5093	1.1811
Observed StDev	Standard deviation of reported mean vitamin C	23.0372	0.0004	325.6956	35.7466
Imputed StDev	Reported and imputed standard deviation combined	21.9114	0.0004	325.6956	30.7990
Processed	Binary variable = 1 if not fresh, = 0 otherwise	0.3855	0	1	0.4869
Frozen	Binary variable = 1 if frozen, = 0 otherwise	0.3063	0	1	0.4612
Canned	Binary variable = 1 if canned, = 0 otherwise	0.0330	0	1	0.1787
Juiced	Binary variable = 1 if juiced, = 0 otherwise	0.0462	0	1	0.2100
Supercenter	Binary variable = 1 if purchased from retail location, = 0 otherwise	0.4533	0	1	0.4981
Storage	Storage time in days between harvest and extraction	47.5446	0	365	96.4897
Cooked	Binary variable = 1 if cooked before extraction, = 0 otherwise	0.1857	0	1	0.3890
No of Determinations	Number of times vitamin C was extracted, the average of which is reported in studies	4.8577	1	69	4.5860

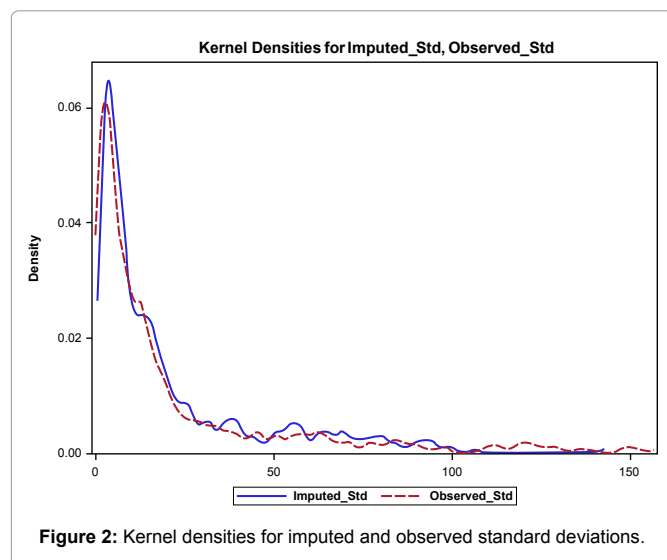


Figure 2: Kernel densities for imputed and observed standard deviations.

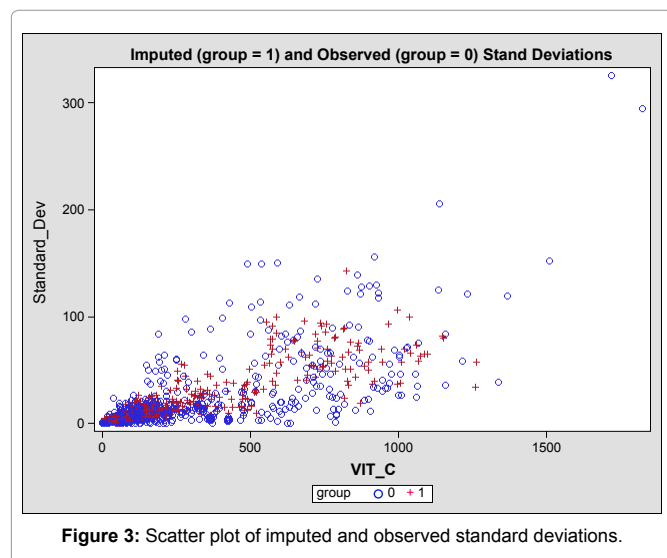


Figure 3: Scatter plot of imputed and observed standard deviations.

deviations (Table 1). The tightness of the imputed values is easily observed in the scatter plot in figure 3, as well.

Statistical methods and analysis

The recent accumulation of research studies and data has not only resulted in a large amount of information available to researchers, but also in the proliferation of sophisticated methodologies to combine and analyze information from a series of related, but independent studies. These studies, if considered separately, would suffer from narrower scope, small sample size, limited geographic coverage and time span, and a myriad of other limitations by definition. The statistical analysis to assimilate the findings in the literature is commonly referred to as meta-analysis [58]. The models were estimated using the mixed model structure. The restricted maximum likelihood (REML) rather than maximum likelihood (ML) method was used, motivated by the fact that it typically provides less biased estimates of the variance component, when the number of groups is small [59].

Two linear equations were estimated using random coefficient modeling:

$$\text{LnVitC}_{ij} = \gamma_{0i} + \gamma_{1i} \text{Processed} + \beta_1 \text{Stor} + \beta_2 \text{StorSq} + \beta_3 \text{Cooked} + \beta_4 \text{Year} + \beta_5 \text{Supercenter} + \varepsilon_{ij}, j=1, \dots, n_i \quad (1)$$

$$\text{LnVitC}_{ij} = \gamma_{0i} + \gamma_{1i} \text{Fzn} + \gamma_{2i} \text{Cnd} + \gamma_{3i} \text{Juc} + \beta_1 \text{Stor} + \beta_2 \text{StorSq} + \beta_3 \text{Cooked} + \beta_4 \text{Year} + \beta_5 \text{Supercenter} + \varepsilon_{ij}, j=1, \dots, n_i \quad (2)$$

where

LnVitC_{ij} is the natural logarithm of the quantity of vitamin C in the i^{th} group;

Processed is a binary variable indicating the form of product as fresh, or processed;

Fzn, *Cnd* and *Juc* indicate whether the product was frozen, canned or juiced, respectively;

Stor is the storage time, in days, before the vitamin C extraction;

StorSq is the squared value of the storage time;

Cooked is a binary variable indicating whether the product was cooked or not cooked;

Year is the year of the analysis;

Supercenter indicates the source of the fruit or vegetable;

γ 's and β 's are the parameter estimates;

$$\text{and } \varepsilon_{ij} = \sim \text{iid } N[0, R], \quad R = \begin{pmatrix} \sigma_\varepsilon^2 & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & \sigma_\varepsilon^2 \end{pmatrix}$$

The natural logarithmic transformation of the dependent variable is used in the models to comply with the normality requirement of the dependent variable for mixed effect modeling. The regressions in (1) and (2) were weighted by the contribution of each observation's inverse variance [60]. The use of an alternative weighting scheme—the standard errors at mean (SEM), has ascertained the robustness of the findings³. The results reported below are obtained from the latter weighting scheme. PROC MIXED in SAS (version 9.2, SAS Institute Inc., Cary, NC, USA) was used to fit the random effects models in (1) and (2) above.

Heterogeneity

The studies in this review differed in objectives, produce varieties, methods of analyses, pre- and post-harvest conditions, geographical location, etc. Likewise, vitamin C values in products can differ based on the product attributes—whether it is a fruit or vegetable, or a root or a leaf, or is orange or dark green, or is high in antioxidant capacity or not, etc.. These sources of heterogeneity were labelled as *Study* and *Product*, respectively. To account for the heterogeneity in the dependent variable not accounted for by the control variables, the possibility that the intercepts and slopes denoted by γ 's in (1) and (2) are random was entertained. The residual covariance matrix *R* was allowed to be of block-diagonal form with the diagonals determined by *Product* or *Study*. The covariance between individual observations is restricted to be identical for products that belong to the same classification group: *My Pyramid*, *My Plate*, *Color*, *TAC*, *Part of Plant*, and *Cluster*.

³We gratefully acknowledge Dr. St-Pierre's personal help on this issue.

Model validation

The choice of random or fixed effects specifications for models (1) and (2) was validated using a string of fit statistics: -2 times the log likelihood, Akaike Information Criterion (AIC) and Schwarz or Bayesian Information Criterion (BIC). These statistics were obtained for all combinations of random effects and variance/covariance specifications of the *R* (residual) matrix. The general rule of selection is the choice of the smallest value. The significant null model likelihood ratio tests (p -value < 0.0001) are used to motivate the choice of random, and/or heterogeneous vs. fixed (null) effects or homogeneous specification.

Results

The extracted estimates and confidence intervals of the processed (from model (1)), and different forms of processed (from model (2)) are presented in table 2 and 3.

In model (1), all random effect and heterogeneity specifications are strict improvements over fixed effect specifications: the null model likelihood ratio tests are invariably significant. The fit criteria indicate that the model with both the intercept and the slope for the processed variable (*Processed*) random, and with the heterogeneity in residual variances defined by *Products* (apples, broccoli), and the heterogeneity in residual co variances defined by the *Part of Plant* classification (potatoes co-vary within the root vegetable group more alike than they co-vary with spinach from another group) is the best choice. That is, the fit criteria have the smallest values. The statistically insignificant parameter estimate for *Processed* in this model indicates that the vitamin C contents are not statistically different in the fresh and processed fruits and vegetables (the null hypothesis that there is no difference between the fresh and processed forms of fruits and vegetables is failed to reject with the probability of $p=0.8654$).

In model (2), again all random effect and heterogeneity specifications are strict improvements over fixed effect and homogeneous residual specifications. Like in model (1), the fit criteria indicate that the model with both the intercept and the slopes for the processed variables (*Frz*, *Cnd*, and *Juc*) specified as random, and with the heterogeneity in residual variances defined by *Products*, and the heterogeneity in residual covariance defined by *Part of Plant* is the best model choice. The insignificant parameter estimates for all forms of processing: freezing, canning and juicing indicate that there is no statistical difference between the fresh and processed fruits and vegetables ($p=0.4437$, $p=0.1808$ and $p=0.8497$, respectively).

Discussion

Low consumption levels of fruits and vegetables have been subjected to scientific and public scrutiny in the recent years. The substitution of expensive and perishable fresh fruits and vegetables with alternatives with longer shelf lives will improve fruit and vegetable intake, and therefore, help meet the recommended levels of vitamin C intake. A literature review and meta-analysis was performed to investigate the vitamin C equivalence between fresh and processed fruits and vegetables.

The resulting database was analyzed using meta-analysis techniques to reveal statistical associations between vitamin C levels and type (fresh or processed) of fruits and vegetables, while controlling for some pre- and post-harvest effects. The results from the random effects models indicate no statistically significant difference between the vitamin C levels in processed and fresh fruits and vegetables. In the same line, the results from a nested model with the disaggregated *processed* variable confirm similar relationships of frozen and canned compared to fresh fruits and vegetables. The robustness of findings was confirmed by using alternative model specifications and weighting

Int means intercept. LCI/UCI means lower/upper confidence interval. Best model choice is boldfaced

Table 2: Model specifications and the parameter estimate (standard errors) [p-values] for the *Processed* variable in Model (1).

Residual Heterogeneity		Random Effects	-2 Res Log Likelihood	AIC	BIC	Null Model Likelihood Ratio Test	Processed	LCI 95%	UCI 95%
Covariance Grouped by Food Groups	Variance Clustered by Subjects								
MyPyramid	Study	Int, Processed	5375.3	5393.3	5410.0	2576.0 [<.0001]	0.0298 (0.2856) [0.9191]	-0.6066	0.6661
MyPlate	Product	Processed	5686.3	5700.3	5714.5	2265.0 [<.0001]	-0.0774 (0.1230) [0.5340]	-0.3279	0.1732
TAC	Product	Int	6601.6	6615.6	6629.8	1349.7 [<.0001]	-0.5488 (0.4383) [0.2108]	-1.4090	0.3113
Part of Plant	Product	Int, Processed	5100.0	5118.0	5136.2	2851.3 [<.0001]	0.0662 (0.3872) [0.8654]	-0.7283	0.8607
Color	Study	Int	5294.2	5312.2	5328.8	2657.1 [<.0001]	-0.1081 (0.1824) [0.5537]	-0.4660	0.2499
Cluster	Product	Int	6613.9	6631.9	6650.1	1337.4 [<.0001]	-0.6659 (0.4518) [0.1408]	-1.5525	0.2207

Int means intercept, Frz means frozen, Cnd means canned, Juc means juiced. LCI/UCI means lower/upper confidence interval. Best model choice is boldfaced

Table 3: Model specifications and the parameter estimate (standard errors) [p-values] for the *Processed* variables (*Frz*, *Cnd*, and *Juc*) in Model (2).

Residual Heterogeneity		Random Effects	-2 Res Log Likelihood	AIC	BIC	Null Model Likelihood Ratio Test	Frz	LCI 95%	UCI 95%	Cnd	LCI 95%	UCI 95%	Juc	LCI 95%	UCI 95%
Covariance Grouped by Food Groups	Variance Clustered by Subjects														
MyPyramid	Study	Int	5391.7	5405.7	5418.6	2544.2 [<.0001]	0.3430 (0.1487) [0.0212]	0.0513	0.6347	-1.0054 (0.1298) [<.0001]	-1.2602	-0.7507	1.7899 (2.1366) [0.4042]	-2.4029	5.9826
MyPlate	Study	Int	5397.2	5411.2	5424.1	2538.7 [<.0001]	0.2088 (0.1555) [0.1796]	-0.0964	0.5140	-0.9267 (0.1232) [<.0001]	-1.1685	-0.6849	1.7786 (2.1366) [0.4053]	-2.4141	5.9713
TAC	Product	Int	6584.0	6598.0	6612.1	1351.9 [<.0001]	0.1064 (0.6657) [0.8730]	-1.1999	1.4128	-1.3871 (0.5972) [0.0204]	-2.5589	-0.2152	0.1086 (0.8444) [0.8977]	-1.5484	1.7657
Part of Plant	Product	Int, Frz, Cnd, Juc	5353.8	5385.8	5418.2	2582.1 [<.0001]	-0.3837 (0.4915) [0.4437]	-1.4059	0.6385	-1.3007 (0.8871) [0.1808]	-3.3463	0.7449	0.3416 (1.5892) [0.8497]	-6.4960	7.1791
Color	Study	Int, Frz, Cnd, Juc	5382.3	5418.3	5451.6	2553.5 [<.0001]	0.1141 (1.0251) [0.9138]	-2.2049	2.4330	-0.9700 (1.8599) [0.6540]	-8.9724	7.0324	0.7469 (2.9909) [-]	-	-
Cluster	Product	Int	6588.1	6606.1	6624.3	1347.8 [<.0001]	0.0708 (0.6293) [0.9105]	-1.1641	1.3056	-1.1456 (0.5569) [0.0399]	-2.2384	-0.0528	0.2560 (2.4071) [0.9153]	-4.4676	4.9797

schemes. Based on the results in this research, the initial hypothesis of the equivalence was maintained, expressed by the vitamin C contents of fresh and processed fruits and vegetables. The findings from this study open up new, alternative dietary patterns that would result in improved vitamin C intake of the population, without major policy intervention or budgetary changes.

References

- U.S. Department of Agriculture and U.S. Department of Health and Human Services. Dietary Guidelines for Americans (2010). (7th Edition), Washington, DC: U.S. Government Printing Office, December 2010.
- Lee SK, Kader AA (2000) Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol Technol 20: 207-220.
- Buzby JC, Wells HF, Kumcu A, Lin BH, Lucier G, et al. (2010) Canned fruit and vegetable consumption in the United States: An updated report to Congress. ERS, USDA.
- Dauthy ME (1995) Fruit and vegetable processing. Food and Agriculture Organization of the United Nations, Rome.
- Hill H (2008) Food Miles: Background and Marketing. ATTRA-National Sustainable Agriculture Information Service.
- Rickman JC, Barrett DM, Bruhn CM (2007) Nutritional comparison of fresh, frozen, and canned fruits and vegetables. Part 1. Vitamins C and B and phenolic compounds. J Sci Food Agric 87: 930-944.
- Rickman JC, Bruhn CM, Barrett DM (2007) Nutritional comparison of fresh, frozen, and canned fruits and vegetables II. Vitamin A and carotenoids, vitamin E, minerals and fiber. J Sci Food Agric 87: 1185-1196.
- Kyureghian G, Stratton J, Bianchini A, Albrecht J (2010) Nutritional Comparison of Frozen and Non-Frozen Fruits and Vegetables: Literature Review. The Food Processing Center University of Nebraska-Lincoln.
- Martin-Belloso O, Llanos-Barrioberro E (2001) Proximate composition, minerals and vitamins in selected canned vegetables. Eur Food Res Technol 212: 182-187.
- Mullen W, Stewart AJ, Lean ME, Gardner P, Duthie GG, et al. (2002) Effect of freezing and storage on the phenolics, ellagitannins, flavonoids, and antioxidant capacity of red raspberries. J Agric Food Chem 50: 5197-5201.
- Zhang D, Hamazu Y (2004) Phenolics, ascorbic acid, carotenoids and antioxidant activity of broccoli and their changes during conventional and microwave cooking. Food Chem 88: 503-509.
- Howard LA, Wong AD, Perry AK, Klein BP (1999) β -Carotene and Ascorbic acid retention in fresh and processed vegetables. J Food Sci 64: 929-936.
- Tudela JA, Hernandez JA, Gil MI, Espin JC (2003) L-galactono- γ -lactone dehydrogenase and vitamin C content in fresh-cut potatoes stored under controlled atmospheres. J Agric Food Chem 51: 4296-4302.
- Bergquist SA, Gertsson UE, Nordmark LY, Olsson ME (2007) Ascorbic acid, carotenoids, and visual quality of baby spinach as affected by shade netting and postharvest storage. J Agric Food Chem 55: 8444-8451.
- Guerrant NB (1957) Food storage effects. Changes in light reflectance and Ascorbic acid content of foods during frozen storage. J Agric Food Chem 5: 207-212.
- Gahler S, Otto K, Bohm V (2003) Alterations of vitamin C, total phenolics, and antioxidant capacity as affected by processing tomatoes to different products. J Agric Food Chem 51: 7962-7968.
- Sanchez-Moreno C, Plaza L, Elez-Martinez P, De Ancos B, Martin-Belloso O, et al. (2005) Impact of high pressure and pulsed electric fields on bioactive compounds and antioxidant activity of orange juice in comparison with traditional thermal processing. J Agric Food Chem 53: 4403-4409.
- Jiratanan T, Liu RH (2004) Antioxidant activity of processed table beets (*Beta vulgaris* var. *conditiva*) and green beans (*Phaseolus vulgaris* L.). J Agric Food Chem 52: 2659-2670.

19. Russell LF (1986) High performance liquid chromatographic determination of vitamin C in fresh tomatoes. *J Food Sci* 51: 1567-1568.
20. Sahari MA, Boostani FM, Hamidi EZ (2004) Effects of low temperature on the ascorbic acid content and quality characteristics of frozen strawberry. *Food Chem* 86: 357-363.
21. Hakala M, Lapveteläinen A, Huopalahti R, Kallio H, Tahvonen R (2003) Effects of varieties and cultivation conditions on the composition of strawberries. *J Food Compos Anal* 16: 67-80.
22. Russell LF, LeBlanc DI, McRae KB, Ryan DAJ (2009) Losses of vitamin C from fresh strawberries in a commercial supply chain. *Int J Food Sci Technol* 44: 820-828.
23. Tosun M, Ercisli S, Karlıdag H, Sengul M (2009) Characterization of red raspberry (*Rubus idaeus* L.) genotypes for their physicochemical properties. *J Food Sci* 74: C575-C579.
24. Gonzalez EM, de Ancos B, Cano MP (2003) Relation between bioactive compounds and free radical-scavenging capacity in berry fruits during frozen storage. *J Sci Food Agric* 83: 722-726.
25. Deighton N, Brennan R, Finn C, Davies HV (2000) Antioxidant properties of domesticated and wild *Rubus* species. *J Sci Food Agric* 80: 1307-1313.
26. Pantelidis GE, Vasilakakis M, Manganaris GA, Diamantidis G (2007) Antioxidant capacity, phenol, anthocyanin and ascorbic acid contents in raspberries, blackberries, red currants, gooseberries and cornelian cherries. *Food Chem* 102: 777-783.
27. Shin Y, Ryu JA, Liu RH, Nock JF, Polar-Cabrera K, et al. (2008) Fruit quality, antioxidant contents and activity, and antiproliferative activity of strawberry fruit stored in elevated CO₂ atmospheres. *J Food Sci* 73: S339-S344.
28. Masrizal MA, Giraud DW, Driskell JA (1997) Retention of vitamin C, iron, and β -carotene in vegetables prepared using different cooking methods. *J Food Qual* 20: 403-418.
29. Vallejo F, Tomas-Barberan FA, Garcia-Viguera C (2002) Glucosinolates and vitamin C content in edible parts of broccoli florets after domestic cooking. *Eur Food Res Technol* 215: 310-316.
30. Hagg M, Hakkinen U, Kumpulainen J, Ahvenainen R, Hurme E (1998) Effects of preparation procedures, packaging and storage on nutrient retention in peeled potatoes. *J Sci Food Agric* 77: 519-526.
31. Warthesen JJ, Vickers ZM, Whitney-West S, Wolf ID (1984) Cookery methods for vegetables: influence on sensory quality, nutrient retention, and energy consumption. *Home Economics Research Journal* 13: 61-79.
32. Lee CY, Downing DL, Iredale HD, Chapman JA (1976) The variations of ascorbic acid content in vegetable processing. *Food Chem* 1: 15-22.
33. Franke AA, Custer LJ, Arakaki C, Murphy SP (2004) Vitamin C and flavonoid levels of fruits and vegetables consumed in Hawaii. *J Food Compos Anal* 17: 1-35.
34. Tee ES, Young SI, Ho SK, Mizura SS (1988) Determination of vitamin C in fresh fruits and vegetables using the dye-titration and microfluorometric methods. *Pertanika* 11: 39-44.
35. Burger M, Hein LW, Teply LJ, Derse PH, Krieger CH (1956) Nutrients in frozen foods: Vitamin, mineral, and proximate composition of frozen fruits, juices, and vegetables. *J Agric Food Chem* 4: 418-425.
36. Cook BB, Gunning B, Uchimoto D (1961) Nutrients in frozen foods, variations in nutritive value of frozen green baby lima beans as a result of methods of processing and cooking. *J Agric Food Chem* 9: 316-321.
37. Krehl WA, Winters RW (1950) Effect of Cooking methods on retention of vitamins and minerals in vegetables. *J Am Diet Assoc* 26: 966-972.
38. Kylen AM, Charles VR, McGrath BH, Schleter JM, West LC, et al. (1961) Microwave cooking of vegetables. Ascorbic acid retention and palatability. *J Am Diet Assoc* 39: 321-326.
39. Van Dyne FO, Bruckart SM, Chase JT, Simpson JI (1944) Ascorbic acid content of freshly harvested vegetables. *J Am Diet Assoc* 20: 153-154.
40. Eaks IL (1964) Ascorbic acid content of citrus during growth and development. *Bot Gaz* 125: 186-191.
41. Favell DJ (1998) A comparison of the vitamin C content of fresh and frozen vegetables. *Food Chem* 62: 59-64.
42. Albrecht JA, Schafer HW, Zottola EA (1990) Relationship of total sulfur to initial and retained ascorbic acid in selected cruciferous and noncruciferous vegetables. *J Food Sci* 55: 181-183.
43. Bushway RJ, Helper PR, King J, Perkins B, Krishnan M (1989) Comparison of ascorbic acid content of super-market versus roadside stand produce. *J Food Qual* 12: 99-105.
44. Kalt W, Forney CF, Martin A, Prior RL (1999) Antioxidant capacity, vitamin C, phenolics, and anthocyanins after fresh storage of small fruits. *J Agric Food Chem* 47: 4638-4644.
45. Drake SR, Carmichael DM (1986) Frozen vegetable quality as influenced by high temperature short time (HTST) steam blanching. *J Food Sci* 51: 1378-1379.
46. Drake SR, Spayd SE, Thompson JB (1981) The influence of blanch and freezing methods on the quality of selected vegetables. *J Food Qual* 4: 271-278.
47. Lane RH, Boschung MD, Abdel-Ghany M (1985) Ascorbic acid retention of selected vegetables blanched by microwave and conventional methods. *J Food Qual* 8: 139-144.
48. Wu Y, Perry AK, Klein BP (1992) Vitamin C and β -carotene in fresh and frozen green beans and broccoli in a simulated system. *J Food Qual* 15: 87-96.
49. Barth MM, Perry AK, Schmidt SJ, Klein BP (1990) Misting effects on ascorbic acid retention in broccoli during cabinet display. *J Food Sci* 55: 1187-1188.
50. Albrecht JA, Schafer HW, Zottola EA (1991) Sulfhydryl and ascorbic acid relationships in selected vegetables and fruits. *J Food Sci* 56: 427-430.
51. de Ancos B, Gonzalez E, Cano MP (1999) Differentiation of raspberry varieties according to anthocyanin composition. *Z Lebensm Unters Forsch A* 208: 33-38.
52. Lee HS, Chen CS (1998) Rates of vitamin C loss and discoloration in clear orange juice concentrate during storage at temperatures of 4-25°C. *J Agric Food Chem* 46: 4723-4727.
53. de O Pineli LL, Moretti CL, dos Santos MS, Campos AB, Brasileiro AV, et al. (2011) Antioxidants and other chemical and physical characteristics of two strawberry cultivars at different ripeness stages. *J Food Compos Anal* 24: 11-16.
54. Lisiewska Z, Kmiecik W (1996) Effects of level of nitrogen fertilizer, processing conditions and period of storage of frozen broccoli and cauliflower on vitamin C retention. *Food Chem* 57: 267-270.
55. Martin ME, Sweeney JP, Gilpin GL, Chapman VJ (1960) Broccoli nutrients, factors affecting the ascorbic acid and carotene content of broccoli. *J Agric Food Chem* 8: 387-390.
56. Pennington JAT, Fisher RA (2010) Food component profiles for fruit and vegetable subgroups. *J Food Compos Anal* 23: 411-418.
57. Rubin DB (1987) Multiple Imputation for Nonresponse in Surveys. John Wiley & Sons, New York.
58. Barbosa-Canovas GV, Altunakar B, Mejia-Lorio DJ (2005) Freezing of fruits and vegetables: An agribusiness alternative for rural and semi-rural areas. Food Agriculture Organization of the United Nations, Rome, Italy.
59. Bauer DJ, Sterba SK, Hallfors DD (2008) Evaluating group-based interventions when control participants are ungrouped. *Multivariate Behav Res* 43: 210-236.
60. St-Pierre NR (2001) Invited review: Integrating quantitative findings from multiple studies using mixed model methodology. *J Dairy Sci* 84: 741-755.

Author Affiliation

Top

¹Department of Food Science and Technology, The Food Processing Center, University of Nebraska-Lincoln, USA

²Department of Food Science and Technology, The Food Processing Center, University of Nebraska-Lincoln, USA