Food Product Environmental Footprint Literature Summary:

Citrus

State of Oregon
DEQ Department of Environmental Quality

with support from
The Oregon Sustainability Board

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September 2017

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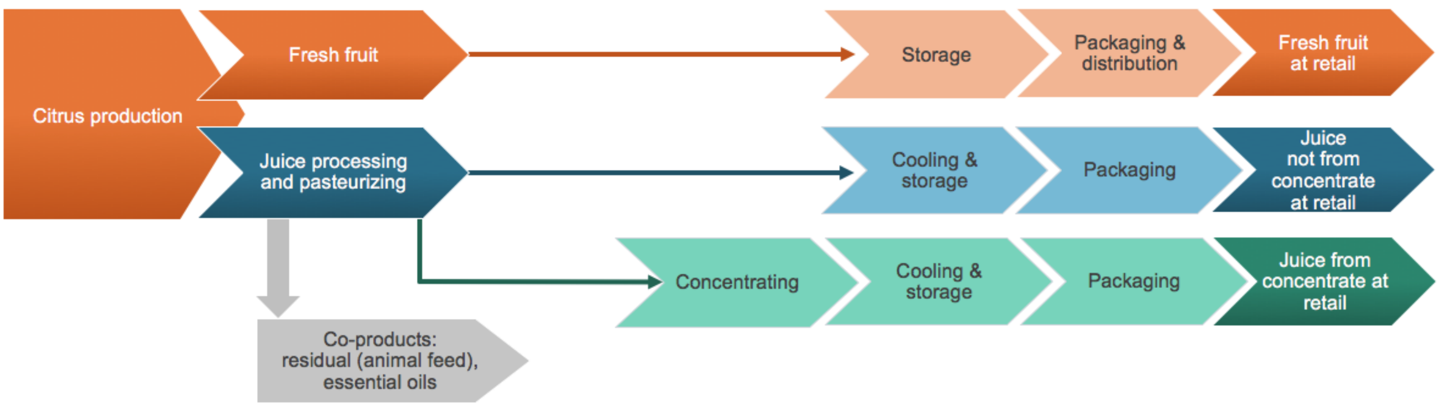
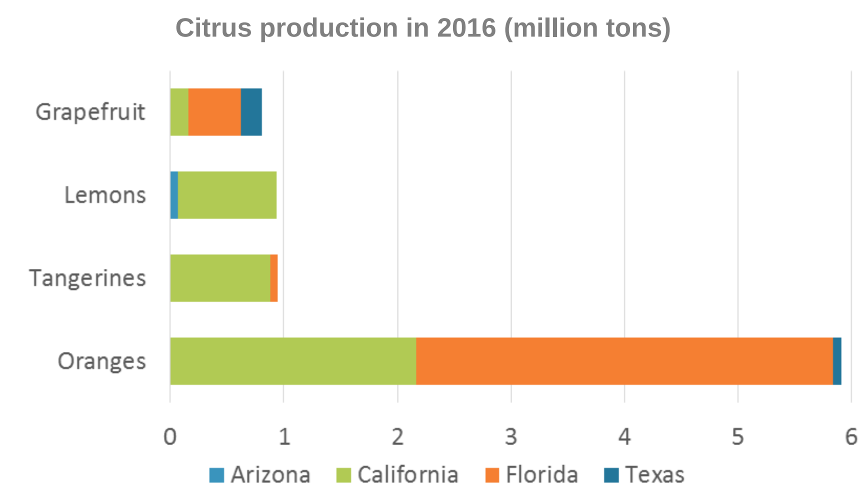
Executive Summary:

Citrus

Citrus represents about 12% of the fresh fruit consumed by Americans. Citrus juices, 90% of which are orange juice, make up 63% of U.S. juice consumption. The purpose of this summary is to highlight what is known about the environmental impacts of citrus production, processing, distribution and consumption based on a review of publically available life cycle assessment (LCA) studies. Even though citrus is not grown in Oregon, the information here may be useful to distributors, retailers, institutional buyers and consumers in making sound environmental decisions. The generic life cycle of citrus production in the U.S. is depicted below.



California and Florida dominate U.S. citrus production as shown in the graph below. However, while 80% of California's crop is marketed as fresh fruit, 90% of Florida's crop is processed. On top of this domestic production, half of the orange juice consumed in the U.S. is imported (likely from Brazil and Mexico), as are half of the lemons and limes (likely from Mexico), and about a quarter of the tangerines and mandarins.

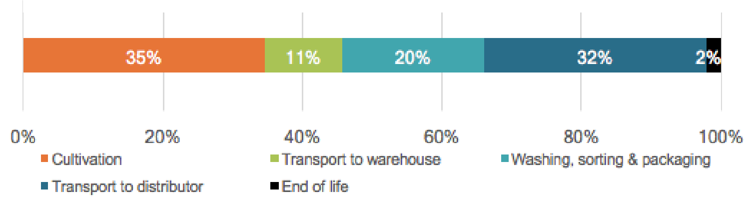


Citrus juices, predominantly orange juice, are available in a number of forms: fresh squeezed, not-from-concentrate, reconstituted from concentrate, or frozen concentrate. Packaging and branding in the marketplace is sometimes confusing to the general public; for example, not-from-concentrate does not necessarily mean freshly processed. Consumer preference for not-from-concentrate juice has all but eliminated the frozen concentrate market in the U.S. Disease pressure and successive hurricanes have significantly impacted Florida citrus growers and have resulted in increased imports from Brazil.

Key Findings

Citrus Agricultural Production

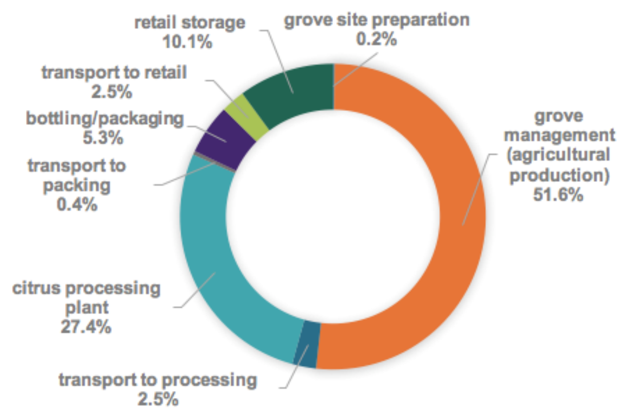
Contribution of life cycle stage to carbon footprint of orange production in Italy



Citrus orchards are often very intensive systems with high inputs of irrigation water, fertilizers, pesticides and fungicides. Fertilizer manufacturing is nearly always a dominant contributor to the carbon footprint. The chart to the right depicts one study that carried the assessment of fresh citrus fruit beyond agricultural production to include sorting and packaging, transport to distributors, and even composting of inedible portions such as peels. Citrus orchards also tend to be high yielding in terms of tons of fruit per hectare in comparison with other perennial tree fruits. Studies that compare conventional and organic orange production show that organic performs better in key impact categories (carbon footprint and others) on a per hectare basis, but yield gaps between conventional and organic may shrink these differences when expressed per kilogram of fruit.

Citrus Juices

Carbon footprint of Florida not-from-concentrate packaged 64 fl oz orange juice



Differences in what is and isn't included in a study (system boundary) and final product make direct comparisons between the handful of studies that consider citrus juices unproductive. Lessons can be learned by considering studies independently, however. One study found that about half of the carbon footprint of a carton of not-from-concentrate orange juice occurs during management of the orange grove, which can be productive up to 30 years (see figure to the right). These agricultural impacts are fairly evenly distributed between energy use in tractors and equipment and material inputs such as fertilizer and pesticides. The juice processing stage, which includes juicing, pasteurization, and storage of not-from-concentrate juice, represents an additional 27%. The results assume a transport distance to retail of 1,000 kilometers (621 miles). Estimating the transport of not-from-concentrate orange juice by truck from Orlando, FL to Portland, OR (3,037 miles) would cause the "transport to retail" stage to go from about 3% to 11% of the total impact and increase the overall carbon footprint of a liter of non-from-concentrate orange juice by nearly 10%.

Conclusions

Results from this review of the life cycle assessment literature on citrus and their juices suggest a few generally applicable conclusions:

- Agricultural production of citrus is an important stage in the product footprint regardless of whether the citrus are consumed fresh or processed into juices. Fertilizer production appears to be a major contributor to on-farm impacts.
- While not unanimously conclusive across the studies reviewed, it appears that organic production of citrus may have an environmental advantage over conventional production even on a product output basis.
- Results indicate that paperboard cartons are a less impactful packaging option for citrus juice than PET bottles.
- Existing evidence is inconclusive regarding whether juice from concentrate (reconstituted by the user) has a lower carbon footprint than not-from-concentrate juice.

Introduction

Citrus represents about 12% of the fresh fruit consumed by Americans. Citrus juices (90% of which are orange juice) make up 63% of U.S. juice consumption[1]. These “sun-kissed” fruits brighten our mornings and help us fend off colds. But what do we know about the environmental footprint left in getting them to our table?

The purpose of this summary is to highlight what is known about the environmental impacts of citrus production, processing, distribution and consumption based on a review of publically available life cycle assessment (LCA) studies. Such studies can identify those parts of the value chain with disproportionately high environmental burdens, allowing improvement efforts to focus where they are likely to have the largest benefits. These LCA studies can also point to potential trade-offs between environmental indicators or abatement strategies. While citrus is not grown in Oregon, the information here may be useful to distributors, retailers, institutional buyers and consumers in making sound environmental decisions.

This literature summary is one of a series commissioned by the Oregon Department of Environmental Quality. For additional information on the background and objectives of these summaries, as well as on LCA methods and definitions of terms, please refer to the Food Product Environmental Footprint Foreword.

California and Florida dominate U.S. citrus production (see Figure 1). However, while 80% of California’s crop is marketed fresh, 90% of Florida’s crop is processed. On top of this domestic production, half of the orange juice consumed in the U.S. is imported (likely from Brazil and Mexico), as are half of the lemons and limes (likely from Mexico), and about a quarter of the tangerines and mandarins[2].

Citrus juices – predominantly orange juice – are available in a number of forms: fresh squeezed (unpasteurized), not-from-concentrate, reconstituted from concentrate, or frozen concentrate (to be reconstituted by the consumer). Packaging and branding in the marketplace is sometimes confusing to the general public; for example, not-from-concentrate does not necessarily mean freshly processed. It is common practice to strip the oxygen from pasteurized orange juice and store it for long periods, and then add back “flavor packs” – collections of chemicals naturally found in oranges that signal ‘freshness’ to consumers – when packaging[3]. Yet, consumer preference for not-from-concentrate juice has all but eliminated the frozen concentrate market in

[1] Percentages on a mass basis. Based on USDA Loss Adjusted Food Availability data: http://www.ers.usda.gov/data-products/food-availability-(per-capita)-data-system/loss-adjusted-documentation.aspx

[2] Citrus: World Markets and Trade. https://apps.fas.usda.gov/psdonline/circulars/citrus.pdf

[3] http://www.wnyc.org/story/last-chance-foods-secret-highly-processed-life-orange-juice/

the U.S. This trend, combined with disease pressure and successive hurricanes have significantly impacted Florida citrus growers and has resulted in increased imports from Brazil[4].

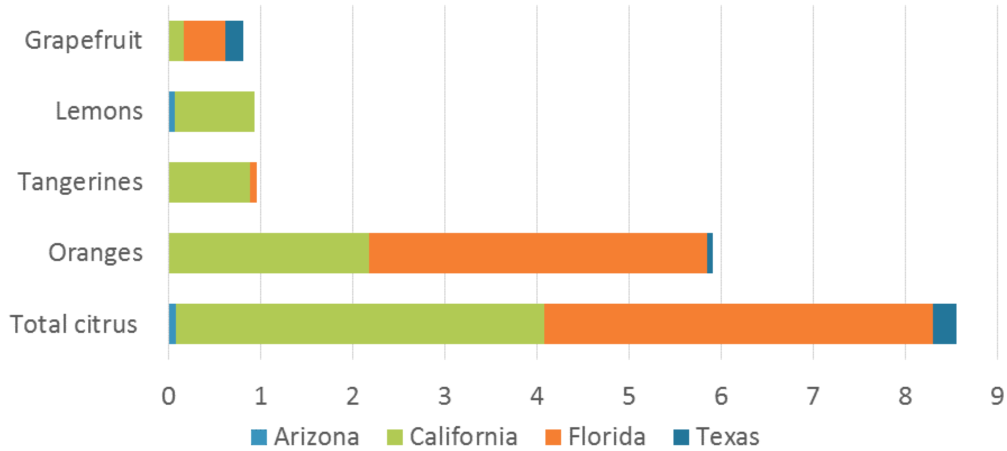


FIGURE 1. U.S. citrus fruit production in 2016. Data from USDA Quickstats.

Available LCA Research

Citrus are commonly consumed both as fresh fruit as well as processed juice, making the life cycle somewhat more complicated than other commodities (see Figure 2). We identified eight LCA studies that look at citrus fruit production. An additional six studies consider fruit production and processing into juices, with some of these including downstream (distribution and retail) stages. Only one of the identified reports looks at U.S. production: Dwivedi *et al*. (2012) consider production of not-from-concentrate orange juice in Florida. The other studies look at citrus production in Brazil, Italy, Spain, and China. Popular media outlets have reported on LCA studies by PepsiCo and Tropicana of their orange juice products, but details of these studies are not publically available and therefore they are not included in this summary.

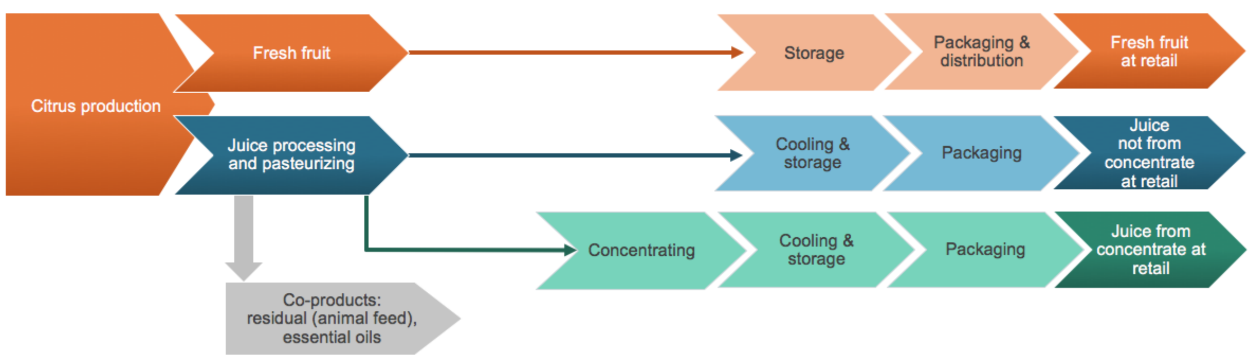


FIGURE 2. Generic life cycle of citrus and juice production.

[4] http://www.wsj.com/articles/the-frozen-concentrated-orange-juice-market-has-virtually-disappeared-1472427124

Key Findings

Citrus Agricultural Production

Citrus orchards are often very intensive systems with high inputs of irrigation water, fertilizers, pesticides and fungicides. They also tend to be high yielding in terms of tonnes of fruit per hectare in comparison with other perennial tree fruits. Averaging 25 production scenarios reported in 11 studies, we found the cradle-to-farm gate carbon footprint of citrus production to be 0.17 kilograms CO_2 equivalents per kilogram fruit (maximum=0.31, minimum=0.04, 95% confidence interval = 0.13-0.21). Fertilizer manufacturing (not including field emissions) is nearly always the dominant contributor to this carbon footprint for the studies that report such disaggregation. Yan *et al.* (2015) report that 90% of greenhouse gas emissions (GHGE) from orange production in China is due to fertilizer use and that there is a strong correlation between carbon footprint per kilogram of fruit and the nitrogen fertilizer applied per kilogram of fruit. They also indicate that China's orchard production has a demonstrated tendency toward excessive nitrogen fertilizer inputs.

Four of the above mentioned studies compare conventional and organic orange (and in one case, orange and lemon) production. All four studies show that organic performs better in key impact categories (GHGE and others) on a *per hectare basis*, but yield gaps between conventional and organic shrink these differences when expressed on a production basis (per kilogram of fruit). Knudsen *et al.* (2011) found that differences between organic and conventional production per kilogram are statistically insignificant. Pergola *et al.* (2013), Ribal *et al.* (2016), and Aguilera, *et al.* (2015), however, all found significant differences, with organic performing better. Ribal, using data from 124 conventional and 153 organic orange farms in Spain, found that the impacts for the average organic farm on a per kilogram basis are statistically lower for abiotic depletion potential, ecotoxicity potential, global warming potential, human toxicity potential, and ozone depletion potential (there were no statistically significant differences for acidification potential, eutrophication potential, and photo-oxidant creation potential).

A few key methodological choices can influence the relative differences between conventional and organic production: whether impacts of manure production are attributed to the generating animal system or the utilizing cropping system, and how changes in soil organic carbon are accounted. Aguilera *et al.* model soil organic carbon sequestration from organic inputs of cover crops, manures, composts, manufactured organic fertilizers, and returned pruning residues. They found that the differences in GHGE per kilogram of product between organic and conventional management were due only to carbon sequestration, as the other reductions in the organic system were offset by lower yields.

One study (Guidice *et al.*, 2013) carried the assessment of fresh citrus fruit beyond the farm gate to include sorting and packaging, transport to distributors, and even composting of inedible portions (i.e., orange peels). Figure 3 shows the GHGE by life cycle stage for this case. Some additional notes are useful in interpreting Figure 3. First, GHGE associated with the orange production stage are on the low end of the range noted above; the reason for this is unclear. Second, while the "washing, sorting & packaging" stage includes production of polypropylene bags for marketing the oranges, cardboard boxes for distribution, and the warehouse building infrastructure where these activities occur (such infrastructure is often excluded from LCAs), 70% of the impact from this stage is due to plastic crates used to transport oranges from the farm. Transport by truck to distribution sites (one 80 kilometers from the packing warehouse, and one 600 kilometers) is a significant contributor to the overall impact. Even with these noted caveats, this study suggests that stages downstream from production may have as great a contribution as those on-farm.

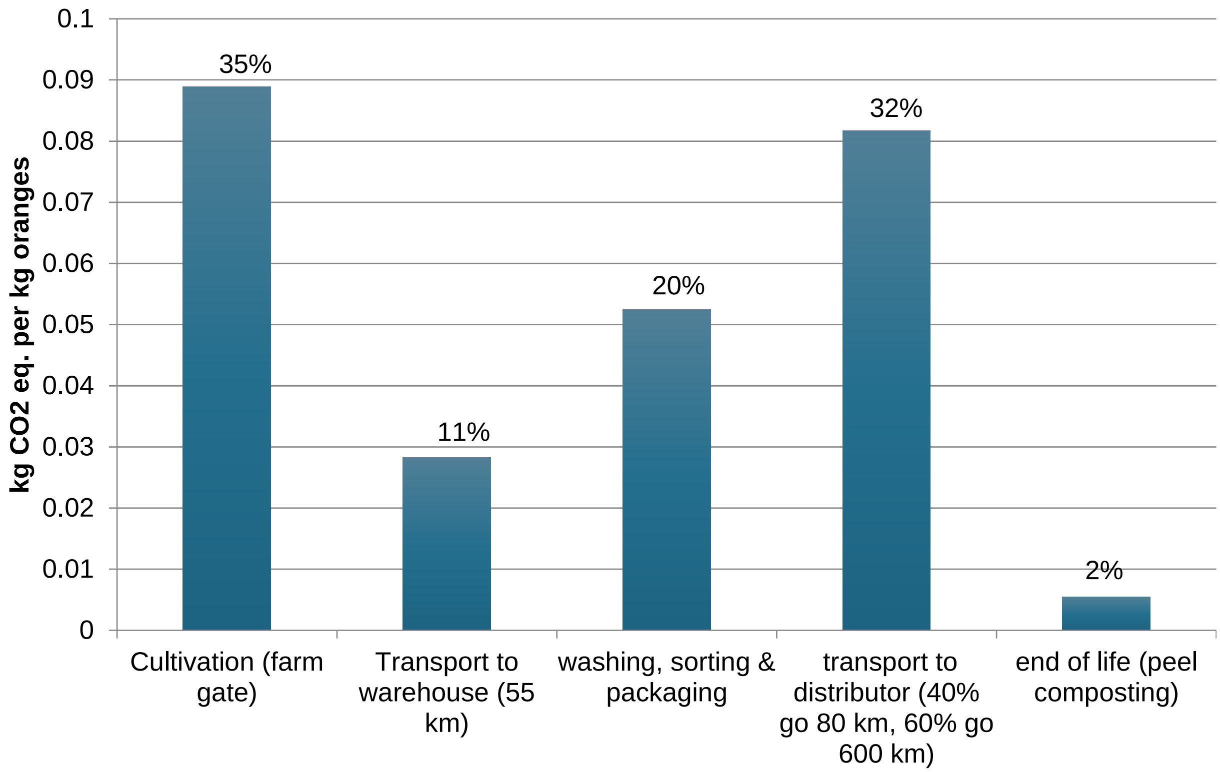


FIGURE 3. Greenhouse gas emissions associated with producing and distributing fresh oranges in Italy, including composting of the inedible portion. Percent contributions to the total are shown above each bar. Adapted from Guidice *et al.*, (2013).

Citrus Juices

Differences in boundary conditions (what is and isn't included in the study) and final product form make direct comparisons between the handful of studies that consider citrus juices unproductive. Lessons can be learned by considering studies independently, however.

Beccali *et al.* (2009) consider the production of both oranges and lemons as well as the processing of these fruits into essential oils, natural juices, and concentrated juices by an Italian manufacturer. As these products share the same initial stages (citrus production and primary processing), allocation of environmental burdens from these stages between the products can strongly influence the results; in this study, this allocation was based on the product's market value (economic allocation). Interestingly, according to data from this Italian manufacturer, orange essential oils represent 40% of their annual sales proceeds (lemon essential oil is 52%); in this study, the oil products, therefore, carry a large portion of the environmental burden of growing the fruit. GHGE connected to growing oranges are 40% higher (per kilogram fruit harvested) than for lemons, and this translates into a similar difference in the carbon footprint of the resulting juices. While this study directly compares "natural" juices and concentrated juices, they do not present this comparison from the standpoint of a final consumed portion of juice. If we assume that reconstitution for consumption involves the same amount of volume change as concentration, then the GHGE affiliated with orange juice from concentrate are slightly higher than "natural" juice (1.2 vs 1.0 kilograms CO_2 equivalents per kilogram consumed juice), largely

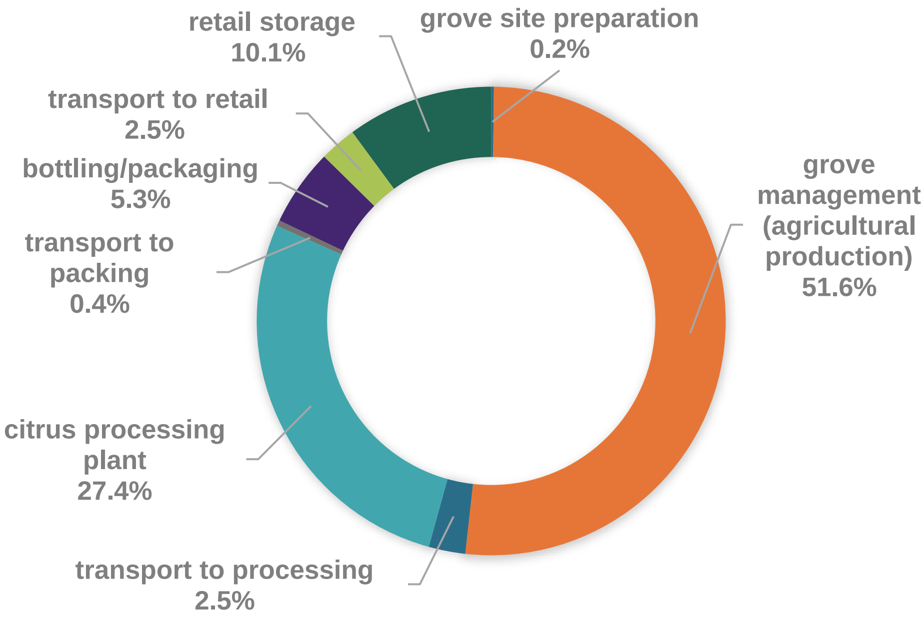


FIGURE 4. Contribution to "cradle-to-retail" carbon footprint of Florida not-from-concentrate orange juice packaged in 64 fluid ounces paperboard cartons and transported 1000 kilometers to retail. Total emissions = 0.84 kilograms CO_2 equivalents per liter of juice (1.6 kilograms CO_2 equivalents per carton). Adapted from Dwivedi *et al.* (2012).

due to the energy needed to concentrate. However, this does *not* include consumer-level packaging or distribution of the packaged product to retail outlets. Concentrated juice likely has an advantage here: less packaging and less weight to ship. For demonstration purposes, transporting regular strength orange juice by truck from Orlando, FL to Portland, OR would add roughly 0.4 kilograms CO_2 equivalents per kilogram juice consumed, whereas transporting 5 times concentrated juice would add less than 0.1 kilograms CO_2 equivalents.

Dwivedi *et al.* (2012) provide a careful account of the global warming impact of Florida's not-from-concentrate (NFC) orange juice, considering a conservative orange grove age of 30 years and based on average state yields and tree mortality rates. They found that about half of the carbon footprint of a carton of NFC orange juice occurs during management of the orange grove (see Figure 4). These agricultural impacts are fairly evenly distributed between energy use in tractors and equipment and material inputs such as fertilizer and pesticides. They considered scenarios both with and without grove resetting (replacing lost trees); resetting is more common (Figure 4 shows the resetting scenario), and by this study's estimates, results in a 10% reduction in GHGE per unit of orange juice. The processing stage, which includes juicing and pasteurization as well as storage of NFC juice, represents an additional 27%. The results in Figure 4 assume a transport distance to retail of 1000 kilometers (621 miles). By our estimates, transporting the NFC orange juice by truck from Orlando, FL to Portland, OR (3,037 miles) would cause the "transport to retail" stage to go from 2.5% to 11.1% of the total impact and increase the overall carbon footprint of a liter of NFC orange juice by 9.7%.

Doublet *et al.* (2013) consider the production of NFC orange juice in Spain, up until it leaves the bottling plant. They found the carbon footprint of NFC orange juice in a 1 liter polyethylene terephthalate (PET) plastic bottle to be 0.67 kilograms CO_2 equivalents per liter. Interestingly, they found that nearly half of this was due to the production of the PET bottle. Results found elsewhere confirm that the impact of PET bottles can be greater than paperboard cartons (the packaging option in the Figure 3 case). This study considers a number of other impact categories; the relative contributions of each stage to these impacts are shown in Table 1. While bottling is a major contributor to climate change and abiotic resource depletion, agriculture is the dominant contributor in other important categories of eutrophication, land use and water depletion.

TABLE 1. Share of environmental impact by major life cycle stages for not-from-concentrate orange juice in Spain. Adapted from Doublet *et al.* (2013).

Impact category	Share contributed from life cycle stage			
	orange production (agriculture)	packing house (sorting, washing)	orange juice processing	bottling process (inc. bottle)
Climate change	25%	3%	22%	51%
Human toxicity, cancer effects	51%	1%	14%	34%
Human toxicity, non-cancer effects	79%	0%	13%	8%
Acidification	51%	3%	17%	29%
Eutrophication, terrestrial	64%	2%	13%	21%
Eutrophication, freshwater	48%	1%	24%	27%
Eutrophication, marine	73%	1%	13%	13%
Ecotoxicity, freshwater	96%	0%	0%	4%
Land use	97%	0%	1%	2%
Abiotic resource depletion	21%	3%	21%	55%
Water depletion	97%	0%	3%	0%

Yet another orange juice study considers the case of organic oranges and frozen concentrated juice produced in Brazil, shipped to Germany for reconstitution, then distributed to Denmark for consumption (Knudsen, *et al.*, 2011). This study found transport to be the major contributor to non-renewable energy use (57%), GHGE (58%), and acidification potential (77%). However, the transport of reconstituted juice from Germany to Denmark (896 kilometers by land) was the most important transportation leg, whereas refrigerated ship transport of frozen concentrated juice from Brazil to Germany (10,040 kilometers) contributed only 3.5% to the total GHGE. If the frozen concentrated juice were instead transported directly to Denmark for reconstitution and bottling, the overall carbon footprint would decrease by 24%. This again emphasizes that fact that transport mode (e.g., truck vs. ocean freighter) can play a bigger role in determining system GHGE than transport distance.

Research Gaps

While a number of LCA studies related to citrus were identified, important questions remain. A publicly available assessment of California citrus doesn't exist. Given the state's important role in supplying the US citrus market, such information would be useful. Mexico is also a major supplier of citrus to the US; an analysis of Mexican citrus production would be a valuable addition. While a number of other important growing regions are represented in the identified literature, it remains unclear if differences seen between these regions are real or due to methodological differences. Most available studies consider oranges. While the few studies that look at other citrus fruits suggest that there aren't major differences, this should be confirmed.

Available studies hint at differences in environmental impact across the life cycle between not-from-concentrate and frozen concentrate juices, but this is not answered completely. Knowing whether reductions in transport burdens can overcome the additional energy needed to concentrate and store frozen concentrate juices could aid institutional buyers looking to reduce their carbon footprint.

Conclusions

Results from this review of the life cycle assessment literature on citrus and their juices suggest a few generally applicable conclusions:

- Agricultural production of citrus is an important stage in the product footprint regardless of whether the citrus are consumed fresh or processed into juices. Fertilizer production appears to be the major contributor to on-farm impacts.
- While not unanimously conclusive across the studies reviewed, it appears that organic production of citrus may have an environmental advantage over conventional even on a product output basis.
- Results indicate that paperboard cartons are a less impactful packaging option for citrus juice than PET bottles.
- Existing evidence is inconclusive regarding whether juice from concentrate (reconstituted by the user) has a lower carbon footprint than not-from-concentrate juice.

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