The Generation of Heat in Fresh Produce

A Working Group on the generation of heat in fresh produce was established by United Fresh Produce Association to examine some of the critical factors involved in the impact of produce temperature on product quality and potentially food safety. This subgroup focused specifically on the generation of heat in fresh produce after harvest and through the fresh processing, cooling, holding and shipment steps to retail, foodservice and ultimately, the consumer. A literature review was undertaken specific to heat generation to determine current research and potential gaps and needs for future research.

Heat generation in fresh produce is primarily developed through respiration, a process where fresh fruits and vegetables use energy from stored reserves and oxygen from the surrounding air to keep the plant alive, even after harvest. Heat, known specifically as "vital heat", is released as a byproduct of the respiration process (Kader, 2002), which contributes to the refrigeration needs that must be considered in designing storage rooms and during transportation of fresh produce (Saltveit, 2016).

Respiration rates vary widely among commodities and even among varieties of the same commodity. Commodities noted for long storage life, such as grapes, apples, cabbage and potatoes, have low respiration rates and produce heat slowly. Vegetables such as peas and asparagus have high respiration rates and produce heat rapidly (Thompson et al, 2008). Management and mitigation of heat from respiratory metabolism in the post-harvest phase of ready-to-eat (RTE) produce for quality management has long been practiced by the fresh-cut produce industry to maximize product shelf-life.

Temperature is the most important factor to control the rate of respiration. Overall, increased temperatures cause an exponential rise in respiration, and therefore heat production. As a rule of thumb, the respiration rate increases 2- to 3-fold for every 10° C (18°F) rise in temperature (Saltveit, 2016). Calculations of heat production from respiration shows that the production of 1 mg of CO_2 yields 2.55 cal. **Tables 1** and **2** in the appendix classify the horticultural commodities according to respiration rate and heat production potential (vital heat; BTU / ton / 24h) at the recommended storage temperature.

In addition to temperature, other key factors that affect fresh produce respiration include:

- Chilling stress
- Heat stress
- Physical stress
- Atmospheric composition

Additionally, growing, processing, storage, and shipment parameters in the production chain can also affect plant- and commodity- specific respiration and subsequent heat generation. These include, among others:

- Genetic factors (variety, regional adaptability)
- Field environmental factors (weather conditions, stress factors such as heat waves, rain, cold, wind, etc.)
- Seasonality and production area
- Cultural practices
- Maturity at harvest
- Cut-to-cool (CTC) timing
- Process timing and temperature control
- Type of fresh-cut processing (shred, cut, slice, etc.)
- Shipment/transportation timing and produce load compatibility.
- Transportation method and temperature controls (refrigerated truck, rail, etc.)

- Distribution center conditions
- Store display case temperature and rotation factor
- Controlled atmosphere (CA) or modified atmosphere packaging (MAP) type

Harvest and postharvest interventions known as Good Agricultural Practices (GAPs) are often utilized by the produce industry to reduce respiration rate and heat generation. Cold chain management is an integral control strategy with variables that include time-temperature CTC management, pre-cooling methodologies (single or double), raw shipping types and methods, temperature management in processing facilities, transportation equipment of refrigerated containers for finished goods (top air delivery vs. bottom air delivery, pallet configuration), retail display equipment selection and temperature management.

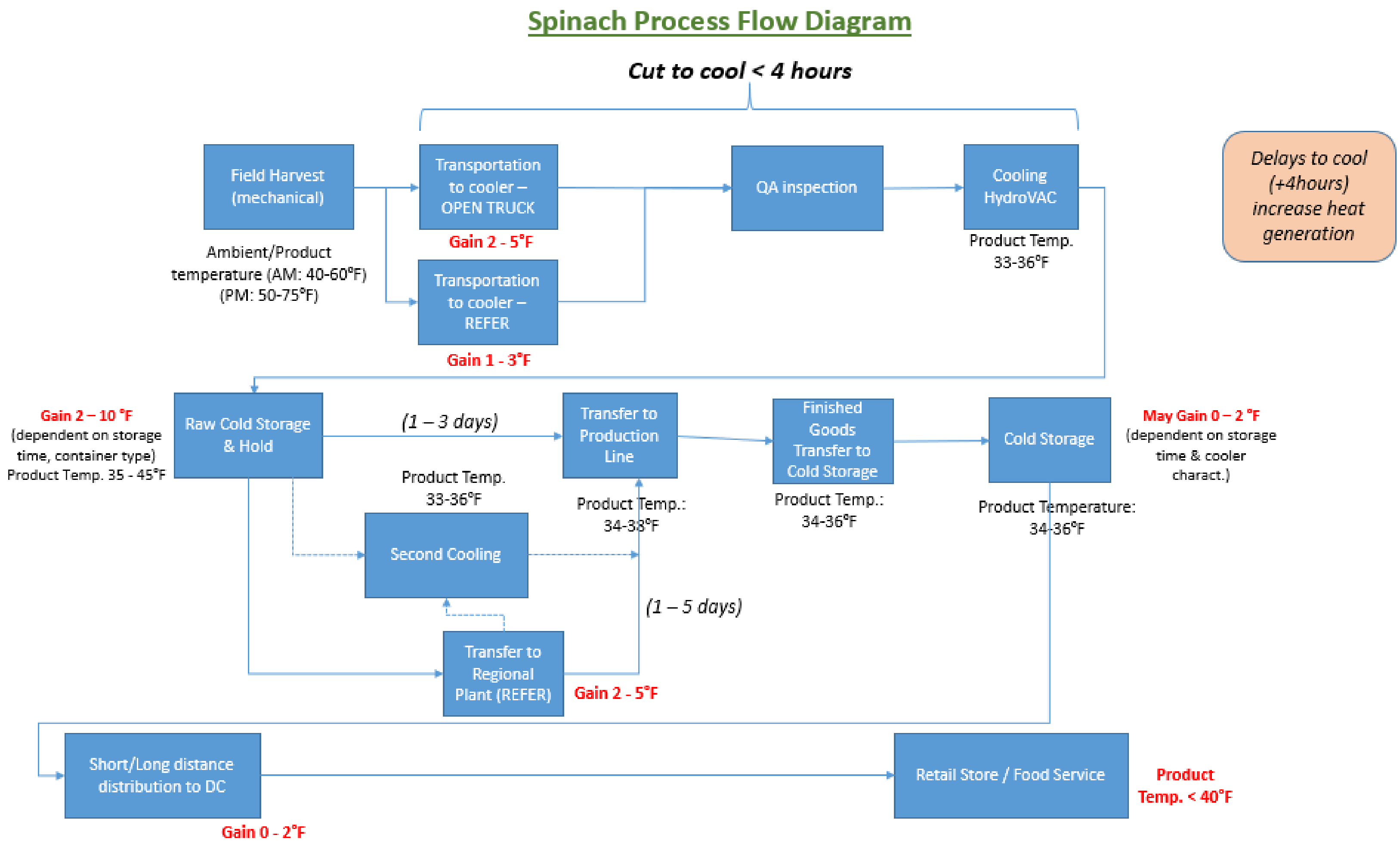
Other postharvest interventions such as the use of modified or controlled atmospheres are considered a supplement to cold chain management. Cantwell & Suslow (2002) found that controlled atmosphere storage can be very effective in maintaining *Brassica* quality. This practice can double postharvest shelf-life according to Izumi et al. (1996). Ideal atmospheres to maintain quality were 1-2% O_2 with 5-10% CO_2 at 0 to 5°C (Cantwell and Suslow, 1997), but if O_2 drops below 1%, off-odors develop (Forney and Rij, 1991). **Table 3** in the appendix illustrates some of these factors in greater detail.

In order to review current industry practices and heat mitigation practices, two example case studies of broccoli and spinach are included below, with product flow charts detailing steps in the supply chain where respiratory heat is generated, as well as examples of current industry “best practices” used to mitigate such respiratory heat generation.

<u>Summary</u>

Maintaining cool environments is a challenge for produce items that, by virtue of their high respiration rates, generate heat. There are several possible mitigations that the industry can take at various points in the supply chain to limit the rate of respiration and reduce the generation of heat. However, there are still many research needs pertaining to factors that influence respiration and mitigations that can be implemented to slow the generation of heat in many commodities. Produce buyers should consider the natural generation of heat as temperature requirements throughout the fresh fruit and vegetable production chain are established.

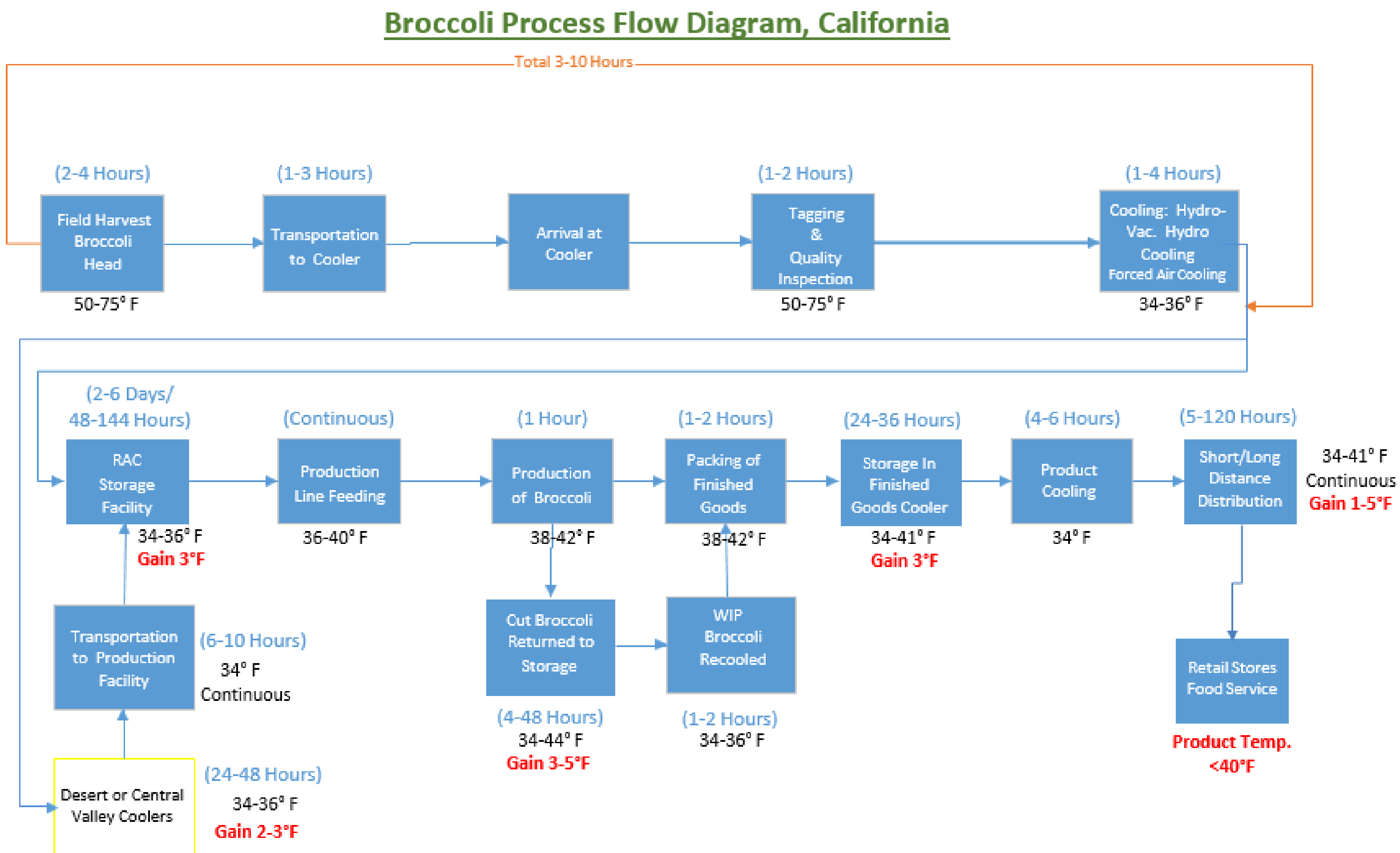
The following is a graphic illustration of fresh spinach flow, and the generation of heat at various stages of the production cycle from harvest through transport to the point of sale:



Note that respiratory heat generation occurrences are noted in red. Many practical methods are currently employed by the fresh produce industry to help mitigate the generation of heat such as:

- Control and minimization of the time from harvest to first cooling (cut-to-cool timing)
- First in/first out product rotation in processing and transport of finished product for quickest post-harvest control
- Often specific to fresh spinach, growers/harvester will utilize bins with a modified interior such as a center cone to help reduce the density of product at harvest and reduce the core temperature within the harvest bin

The following is the graphic illustration of fresh broccoli flow, and the generation of heat at the various stages of the production cycle from harvest through transport to the point of sale:



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Appendix

Table 1: Horticultural commodities classified according to respiration rates and vital heat at 41°F (Adapted from Kader, 2002)

Class	Respiration Rate at 41ºF (mg CO_2/kg-h)	Vital Heat at 41ºF (BTU/ton/24 h)	Commodities
Very Low	< 5	< 1,100	Dates
			Dried fruits & vegetables
			Nuts
Low	5 - 10	1,100 - 1,200	Apple
			Beet
			Celery
			Citrus fruits
			Cranberry
			Garlic
			Grape
			Honeydew melon
			Kiwifruit
			Onion
			Papaya
			Persimmon
			Pineapple
			Pomegranate
			Potato (mature)
			Pumpkin
			Sweet Potato
			Watermelon
			Winter Squash
Moderate	10 – 20	2,200 – 4,400	Apricot
			Banana
			Blueberry
			Cabbage
			Cantaloupe
			Carrot (topped)
			Celeriac
			Cherry
			Cucumber
			Fig
			Gooseberry
			Lettuce (head)
			Mango

Moderate (cont.)	10 – 20	2,200 – 4,400	Nectarine
			Olive
			Peach
			Pear
			Plum
			Potato (immature)
			Radish (topped)
			Summer Squash
			Tomato
High	20 – 40	4,400 - 8,800	Avocado
			Blackberry
			Carrot (with tops)
			Cauliflower
			Leek
			Lettuce (leaf)
			Lima bean
			Radish (with tops)
			Raspberry
			Strawberry
Very High	40 - 60	8,880 - 13,200	Artichoke
			Bean sprouts
			Broccoli
			Brussel Sprouts
			Cherimoya
			Cut flowers
			Endive
			Green Onions
			Kale
			Okra
			Passion Fruit
			Snap Bean
			Watercress
Extremely High	> 60	> 13,200	Asparagus
			Mushroom
			Parsley
			Peas
			Spinach
			Sweet Corn

Table 2: Vital heat of selected fruits and vegetables at near their recommended lowest safe long-term storage temperature, in order of maximum increasing respiration rate (Adapted from Thompson et al., 2008).

Class	Commodities	Recommended Storage Temperature (ºF)	Vital Heat (BTU/ton/24 hrs)
Very Low	Dates		< 220
	Dried fruits & vegetables		
	Nuts		
Low	Grapes	32	220 - 240
	Plum	32	220 - 660
	Kiwifruit	32	660
	Onion (dry)	32	660
	Apple	32	220 - 880
	Cherry	32	880 - 1,100
	Peach	32	880 - 1,300
	Cabbage	32	880 - 1,300
	Orange	41	880 - 1,500
	Beet (topped)	32	1,100 - 1,500
	Pear (Barlett)	32	660 - 1,500
	Radish (topped)	32	660 - 2,000
	Potato	39	660 - 2,000
	Turnip	32	660 - 2,000
	Watermelon	32	660 - 2,000
	Grapefruit	50	1,500 - 2,000
Moderate	Kohlrabi	32	2,200
	Pepper (sweet)	50	3,100
	Lettuce (head)	32	1,300 - 3,700
	Strawberry	32	2,600-4,000
	Squash (summer)	41	3,100-4,200
	Cauliflower	32	3,500-4,200
	Blackberry	32	4,000-4,400
	Carrot (topped)	32	2,200-4,400
	Broccoli	32	4,200-4,600
	Spinach	32	4,200-4,800
	Brussel Sprouts	32	2,200-6,600
	Onion (mature green)	32	2,200-7,000
High	Sweet Potato	59	4,400-5,300
	Raspberry	32	4,000-5,500
	Bean Sprouts	32	4,600-5,500
	Lettuce (leaf)	32	4,200-5,900

High (cont.)	Tomato (green)	59	3,500-6,200
	Cucumber	50	5,100-6,400
	Snap bean	41	7,700
	Parsley	32	6,600-8,800
	Mushroom	32	6,200-9,700
	Artichoke	32	3,300-9,900
	Corn (sweet)	32	6,600-11,200
Very High	Mango	59	9,900
	Endive	32	9,900
	Peas (shelled)	32	10,300-16,500
	Asparagus	32	5,900-17,600

Table 3: Factors impacting respiration-induced heat generation in fresh produce by unit operation, mitigation strategies to control respiration, and current research gaps

Product State	Unit Operation	Factors Affecting Potential Heat Generation	Impact on Respiration Rate and Product Temperature	Current Mitigation Practices	Research Gaps
Raw product - No refrigeration	Growing	**Environmental factors**	Stressed product = higher respiration rate = higher heat production	Unavailable - often unmanageable in field production	No clear information about the impact of environmental conditions in postharvest respiration rate and heat production potential
		Seasonality (e.g.: CA & AZ transition times)			
		Specific environmental conditions (heat waves, unusual cold temperatures, rain, etc.)			
		Agronomic practices			
		Nitrogen fertilization			
		Variety Selection	Dependent on particular variety	Variety selection	
		Maturity	The younger the product = the higher the respiration rate		
	Harvest	Time of harvest (day vs. night)			
		Harvest container type, net weight and venting requirements	Air flow circulation is needed to remove excess vital heat	Optimal selection of harvest container (tote vs. bin; plastic vs. fiber). Use of venting cones for bins	
	Field Transportation	Open air vs. Refer			
		Cut-to-cool (CTC) times	Extended CTC times (> 4 hours) increases respiration rate and heat generation potential	Optimize CTC times	
Raw product –Refrigerated	Pre-cooling	Cooling method and target temperature	Effective removal of field heat	Optimize cooling methods and cycles. Temp target should be 32 - 34ºF	
	Cold storage	Container type and venting requirements	Air flow circulation is needed to remove excess vital heat	Optimal selection of harvest container (tote vs. bin; plastic vs. fiber). Use of venting cones for bins	
		Storage duration	Extended storage time with poor air circulation may promote heat generation	Double cooling when temperatures >38ºF	

	Raw Cold Transportation	Container type and venting requirements	Air flow circulation is needed to remove excess vital heat	Optimal selection of harvest container (tote vs. bin; plastic vs. fiber). Use of venting cones for bins	
		Loading configuration			
		Transport duration			
Finished Goods - Refrigerated	**Fresh-cut processing**	ATU (Age at the Time of Use)	Extended storage time with poor air circulation may promote heat generation	Double cooling when temperatures > 38F	
		Processing temperatures (air & flumes)	Potential heat transfer from air and flumes	Optimal cold chain management at processing facility	
		Packaging			
		MAP design	Improper package design (film structure, OTR, perforations, etc.) may promote heat generation	Optimal MAP design	
		Package material temperatures	Potential heat transfer from packaging materials	Refrigerated packaging materials	
	Finished Goods Cold Transportation	Finished Product temperature			
		Loading configuration			
		Transport duration			