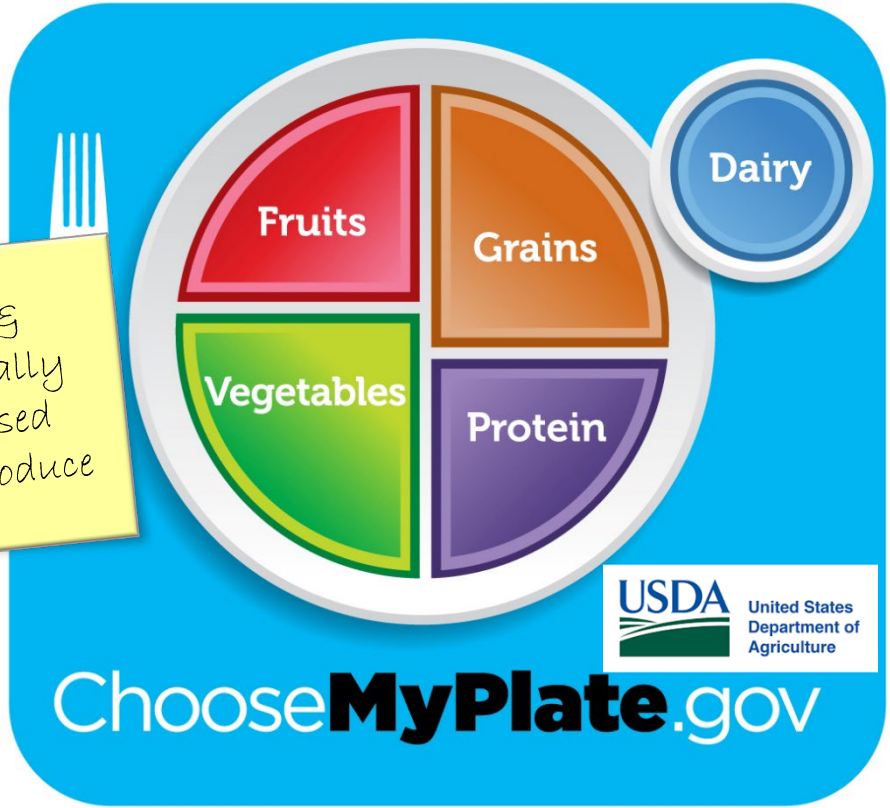
Empa
Materials Science and Technology

"From flower to fork" – Digitale Zwillinge zur Optimierung von Lebensmittelproduktionsprozessen und Lieferketten

24/04/2024 – Thijs Defraeye

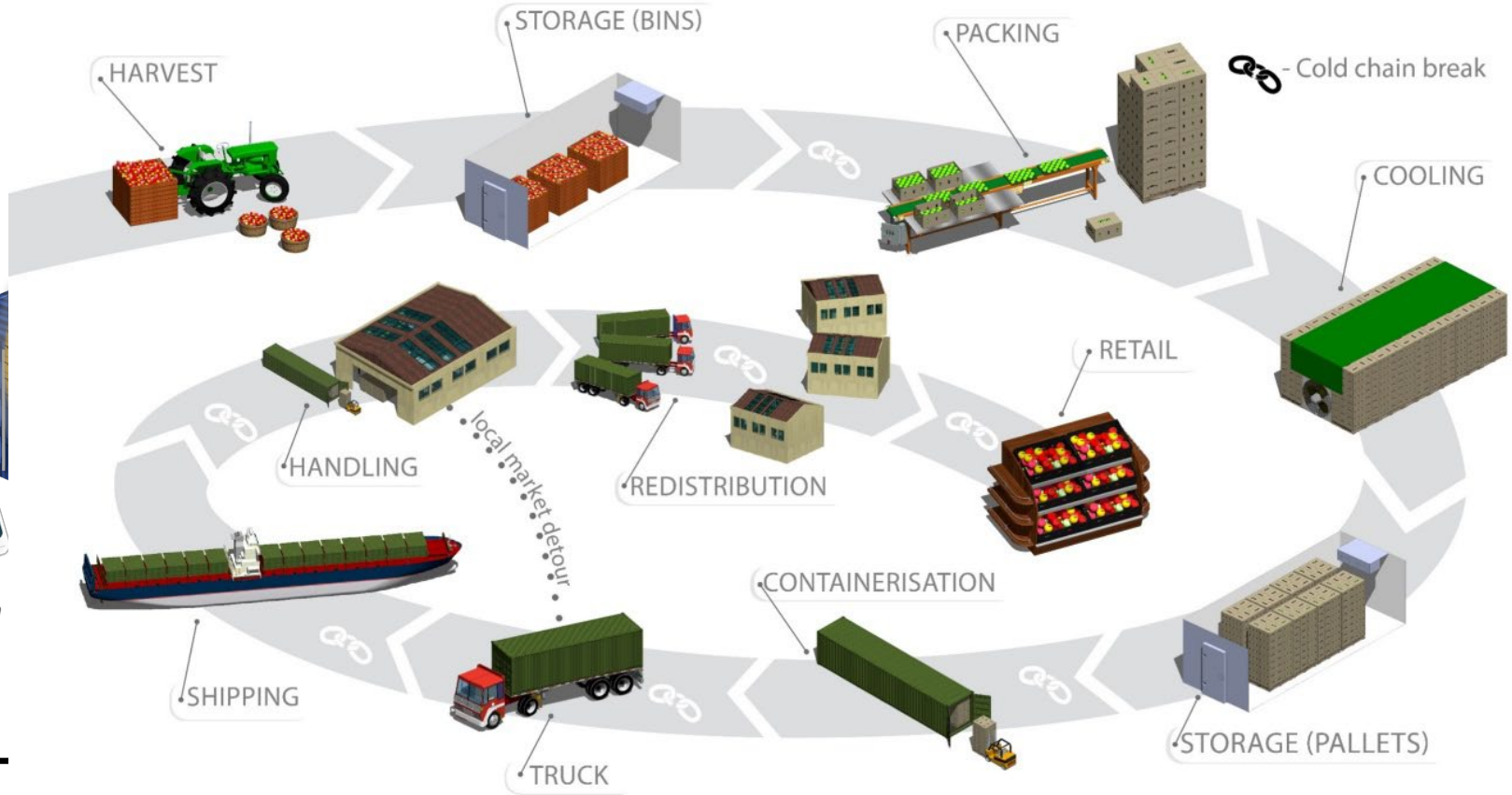
What do we do?

Raw & minimally processed fresh produce



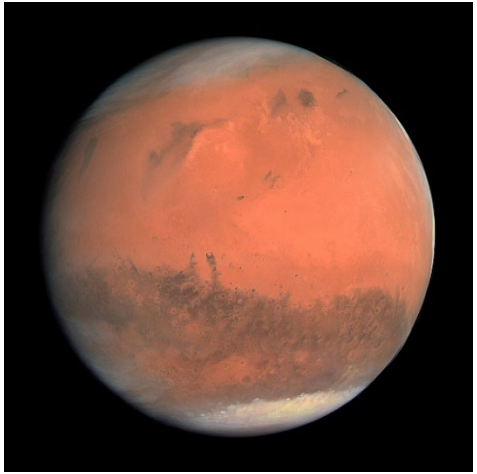
https://www.choosemyplate.gov/
https://eatforum.org/eat-lancet-commission/

What do we do?



Berry, Defraeye et al. (2022), Food and Bioproducts Processing
Shrivastava, Defraeye et al. (2022), Nature Food

Why we work?



Reduce post-harvest losses farm2fork

ID when & why food is lost

commons.wikimedia.org

What is going wrong?

Energy use

Env. impact

Biological variability

Incentives

Delivery air temperature

°C

< -0.6 °C

Accelerated quality loss

Pest infestatio

Chilling injury

USDA

Understand this for each supply chain & country

obiological
k due to
lensation

90 - 95%

Moisture loss

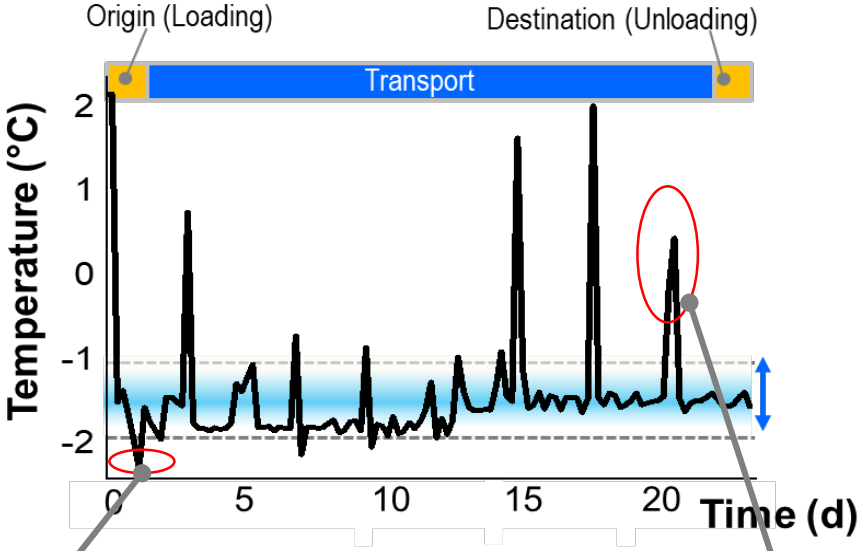
Delivery air relative humidity

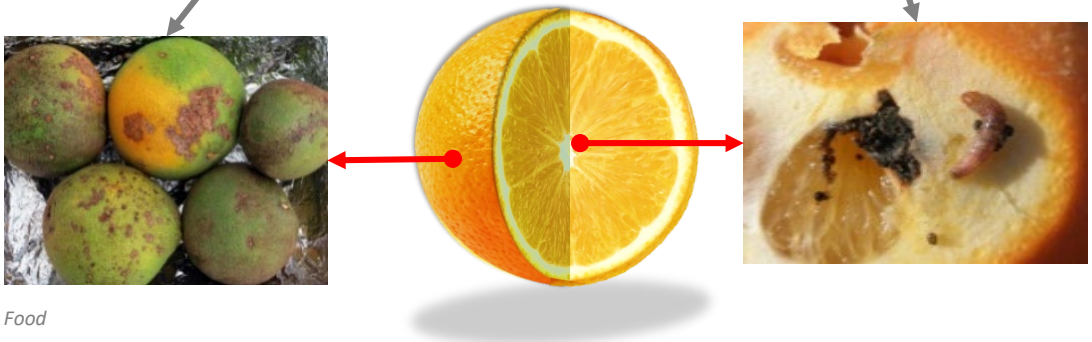
Trade-offs

Flaticon.com, brianphilipkatz.blogspot.com

Where do we start from?

Is our data actionable?

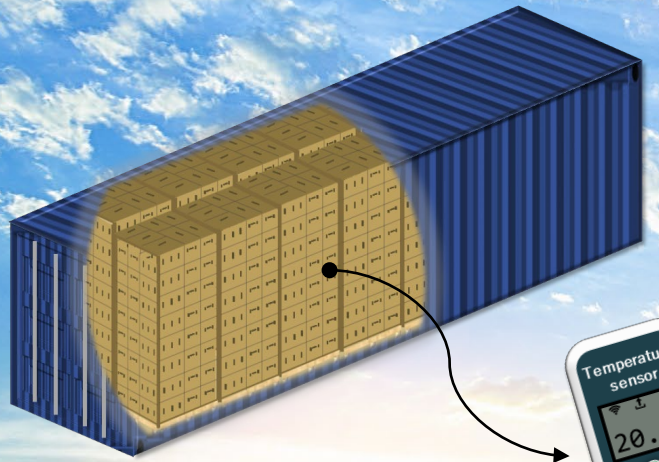


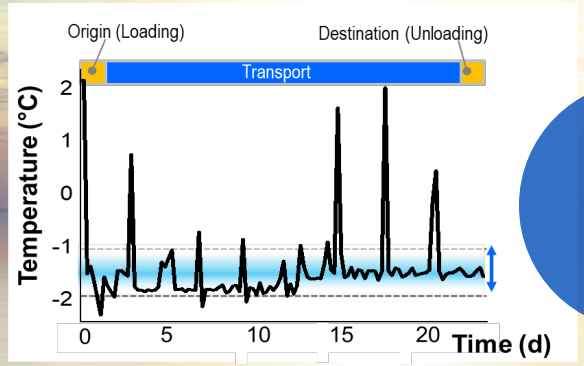


We upcycle data to actionable metrics

Shrivastava, Defraeye et al. (2022), Nature Food

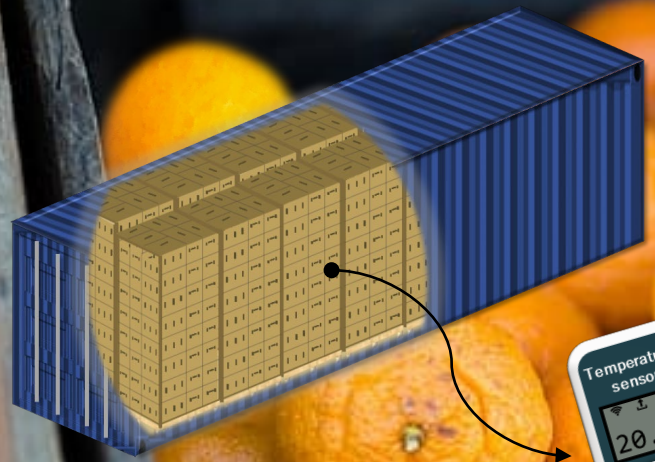
Let's upcycle these data by physics-based simulations

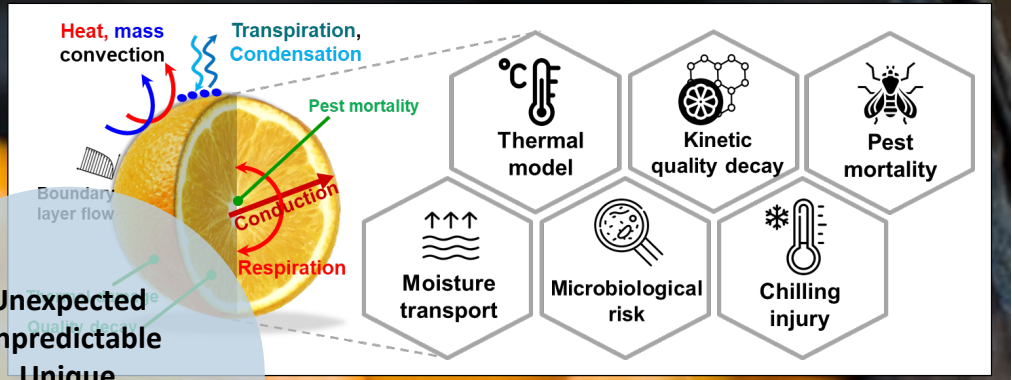




Sensing drivers

Towards digital twins





Unexpected
Unpredictable
Unique

LIFECYCLE

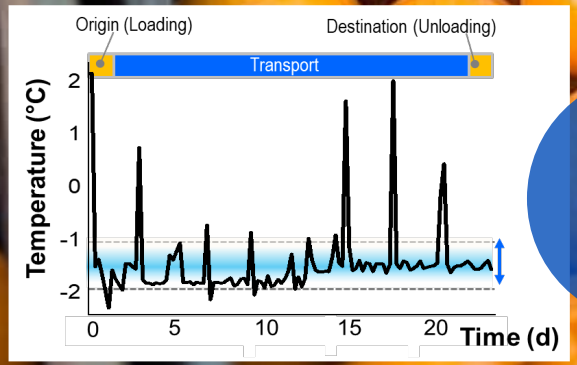
DIGITAL TWIN

Predict

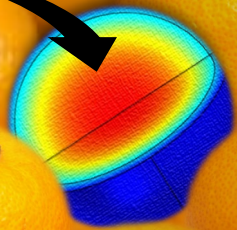
Diagnose

Prevent

Sensing drivers

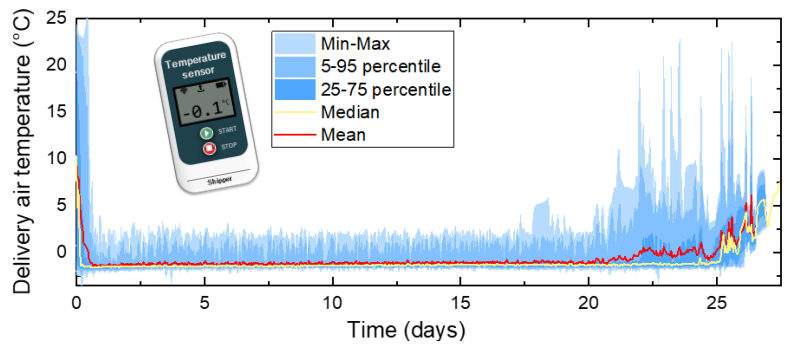


Complementary data

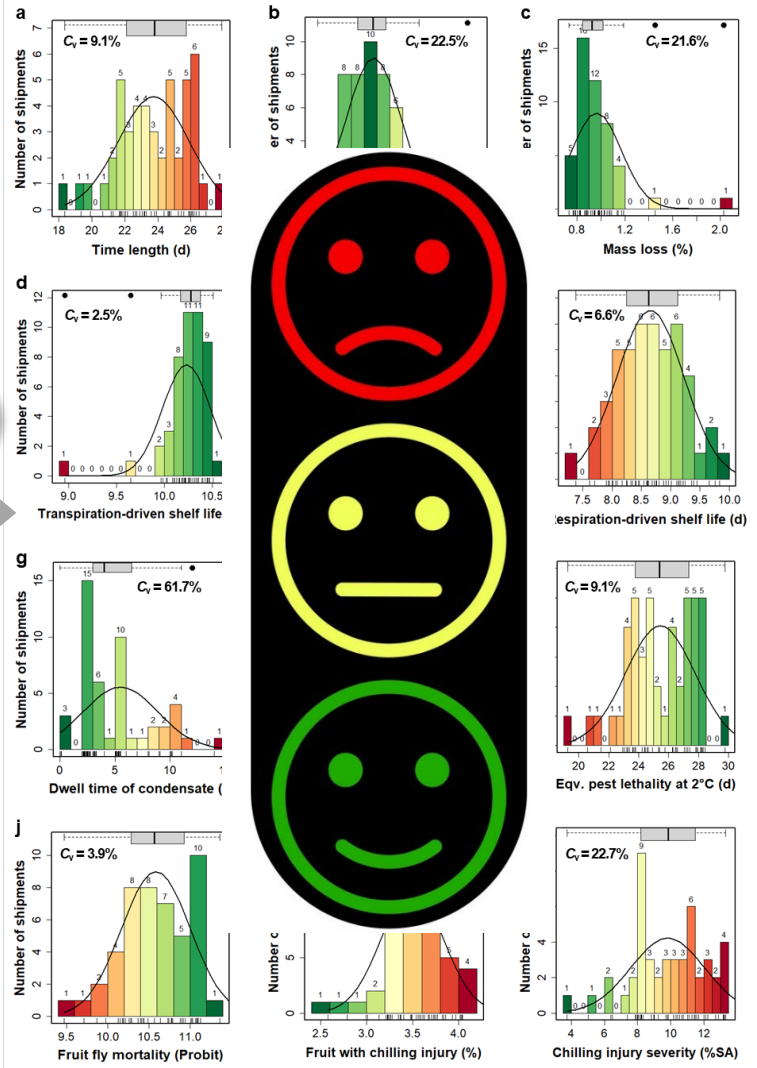


Actionable metrics

From data to more data …
… to less data



Decision making

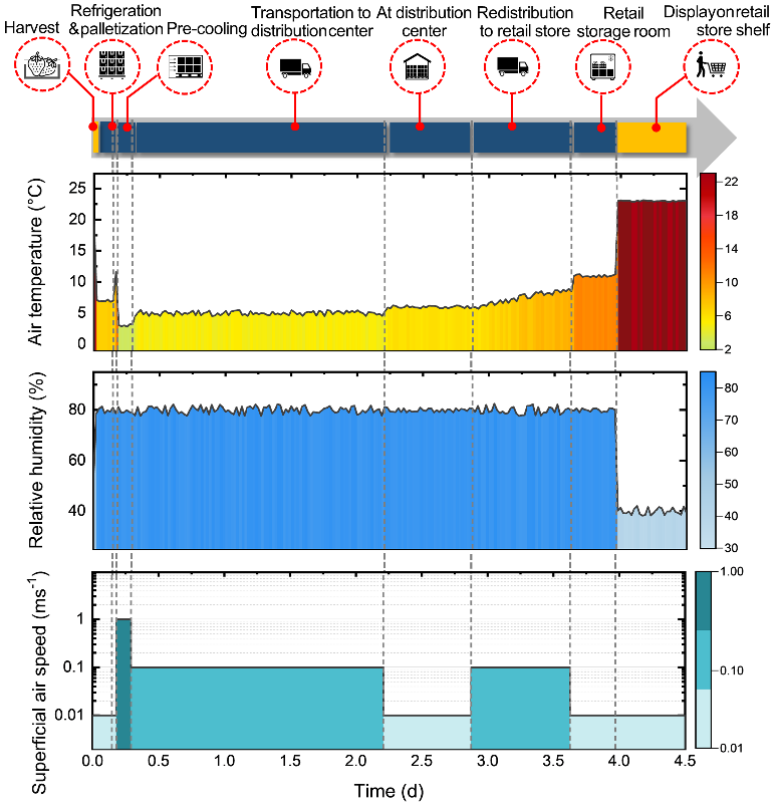


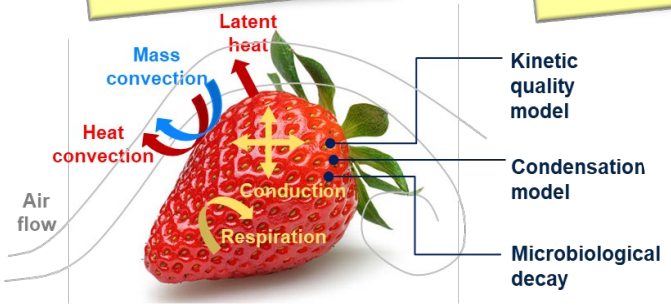
Flaticon.com, istockphoto.com
Shrivastava, Defraeye et al. (2022), Nature Food

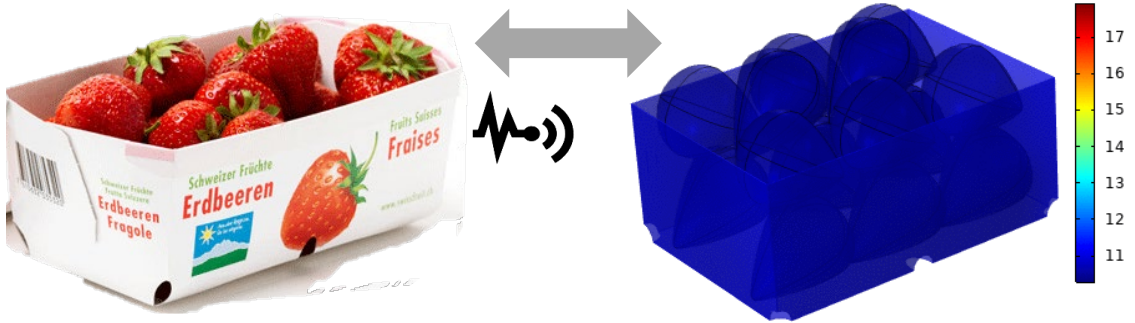
How can digital twins help?

Step away from trail & error design

Best ventilated packaging from farm to retail

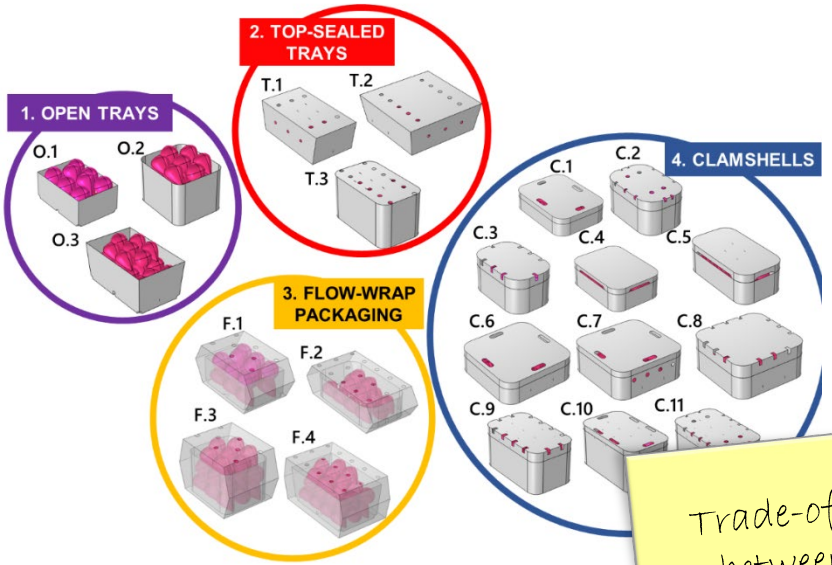




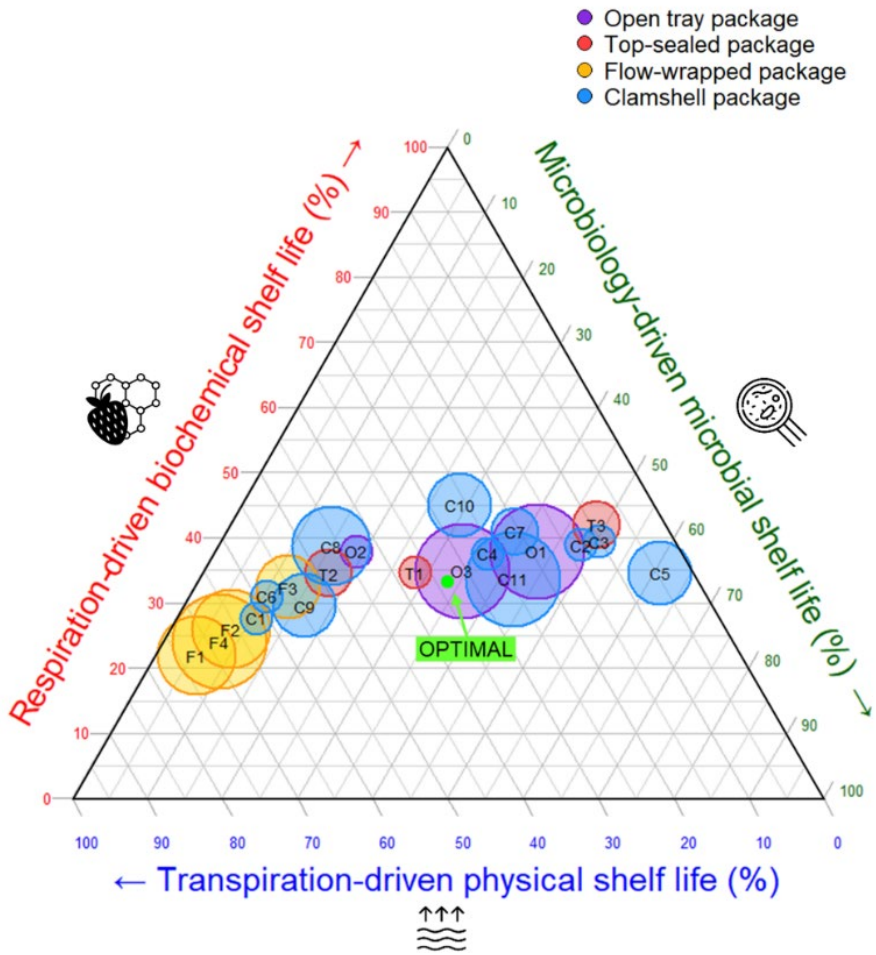


Shrivastava, Onwude, Pereira da Silva, Turan, Paillart, Defraeye et al., Postharvest Biology and Technology (2023)

How can digital twins help?



Trade-offs between packaging designs



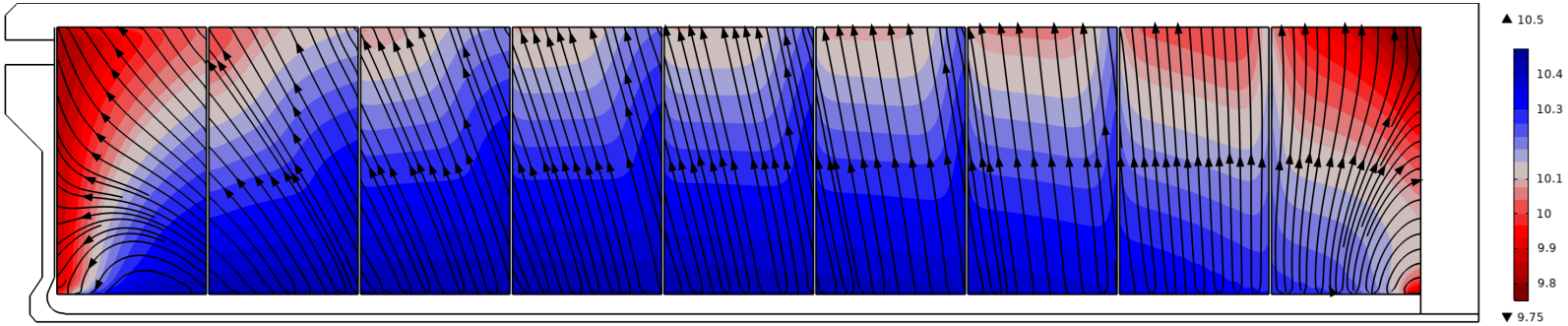
Shrivastava, Onwude, Pereira da Silva, Turan, Paillart, Defraeye et al., Postharvest Biology and Technology (2023)

Temperature in air & temperature in fruit [°C]

identify worst locations

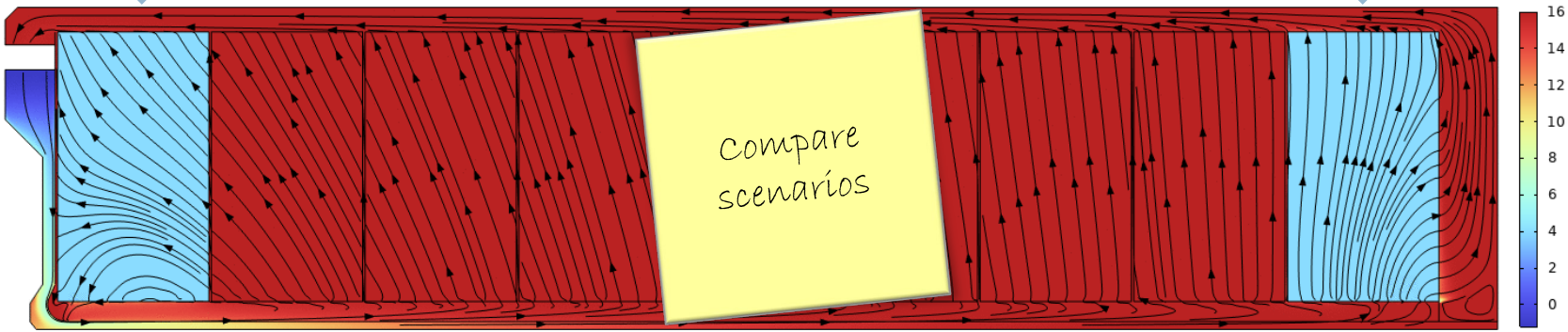
Sensor placing & Quality control

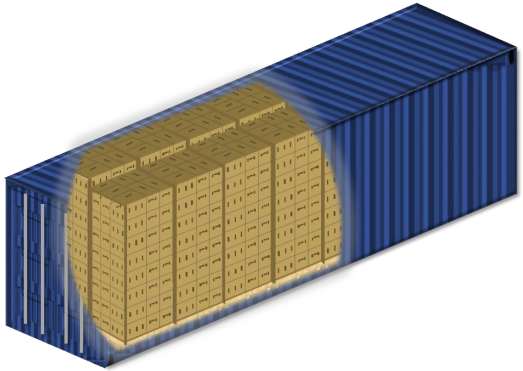
Remaining shelf life after a transport time of 24 days [days]



Defraeye et al., Postharvest Biology and Technology (2024)

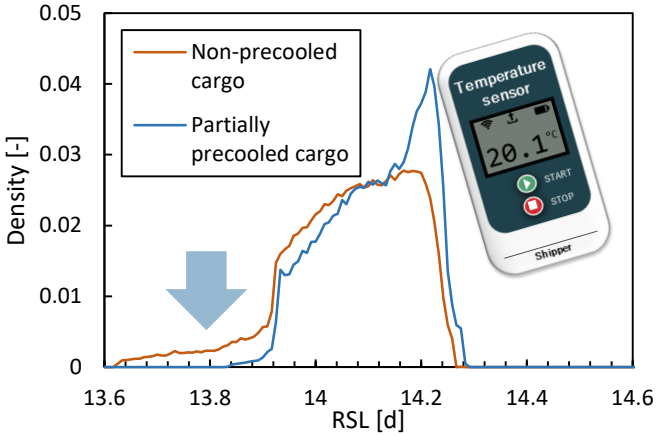
Temperature in air & temperature in fruit [°C] over 3 days





Place 60'000 virtual sensors

Remaining shelf life after 5 days (RSL)



Defraeye et al., Postharvest Biology and Technology (2024)

Integrate in existing supply chains

GROWING CONDITIONS

tree_row_width_m
orchard_code
tree_width_m
production_area
rootstock
growing_month
season_year
growing_system
age_of_trees

WEATHER

temperature_min_outside_degc
temperature_avg_outside_degc
temperature_outside_degc
humidity_outside_pcnt
wind_speed_avg_ms
wind_direction_class
rainfall_mm
wind_direction_degrees
sunshine_hours_unhours
year
wind_speed_ms
temperature_max_outside_degc
humidity_avg_outside_pcnt

COMMODITY INFO

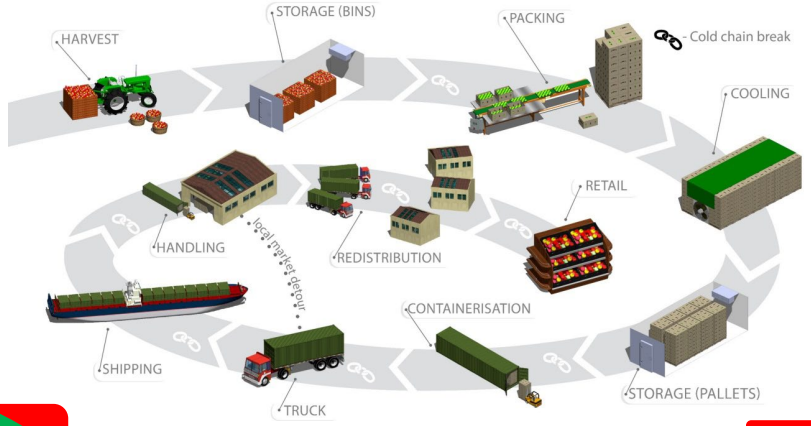
total_open_area_vertical_pcnt
product_grade_count
harvest_time
product_group
product_species
supplier
product_cultivar_variety
producer_code
harvest_week
product_size_mm
product_rind_thickness
total_open_area_horizontal_pcnt

SHIPMENT INFO

duration_dispatch_to_shipment_hours
state_unit
trip_duration
end_date_eta
transport_checked
start_date_etd
starting_port
precooling_checked
carrier
serial_number_shipment
distribution_center
ca_conditioned
duration_etd_to_eta_days

PACKAGING

duration_harvest_to_pack_h
product_weight_per_carton_kg
carton_dimensions_lwh_mm
carton_type
pack_date
subpackaging_type
cartons_per_palette
packaging_type
products_per_carton
packhouse_location
carton_volume_mm
subpackaging_present
pallet_dimensions_lwh_m



SENSORS

end_sensor_logging
range_sensor_temp
airspeed
pulp_temperature_at_end
gas_concentration_o
gas_concentration_co
sensor_placement
air_temperature_degc
sensor_type
light
acceleration
serial_number_monitor
geo_location
interval
logging
start_sensor_logging
air_humidity_pcnt
pulp_temperature_degc
gas_concentration_ch

DIGITAL TWIN AUGMENTED INFO

titratable_acidity_pcnt
pest_incidence_pcnt
pest_mortality
chilling_injury_incidence_pcnt
shelf_life_microbiological_based_d
shelf_life_respiration_based_d
mold_pcnt
shelf_life_transpiration_based_d
firmness_n
color
mold_incidence
mass_loss_pcnt
chilling_injury_incidence_degree
soluble_solids_degbrix
ripeness_degree

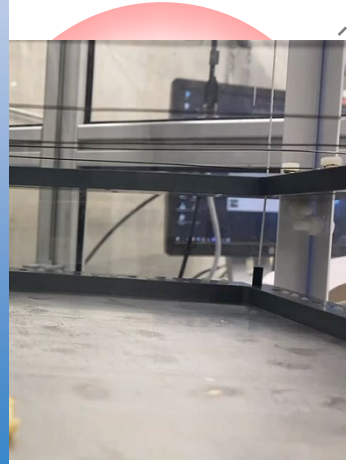
QUALITY CONTROL

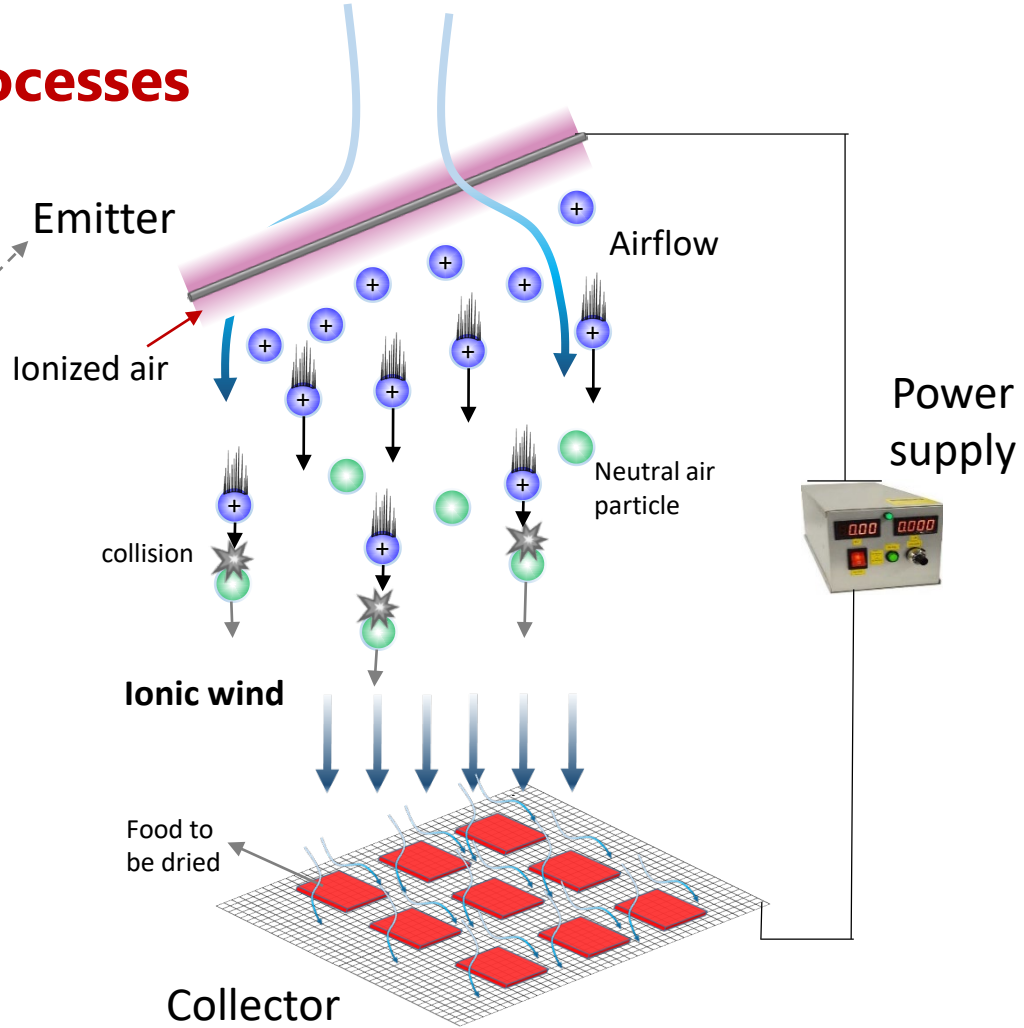
soluble_solids_degbrix
white_shoulders
microbiological_spoilage_incidence
dry_bruising_degree_pcnt
mold_pcnt
mass_loss_pcnt
chilling_injury_incidence_pcnt
color
mold_incidence
quality_rating_score_shipment
firmness_n
reject_shipment
rind_disorder_pcnt
weight_fruit_kg
chilling_injury_incidence_degree
pest_incidence_pcnt
wet_bruising_degree_pcnt

TRANSPORT OPERATION

refrigeration_unit_manufacturer
transport_unit_dimensions
transport_unit_manufacturer
bill_of_lading_cmr
chute_present
mode_of_transport
refrigeration_unit_type
loading_time
arrival_location_port
container_number
start_location_port
transport_type
pallets_in_transport
fan_rpm
carrier_transport_company
refrigeration_unit_other_specs
return_air_temp_degc
cooling_protocol

Optimizing food drying processes



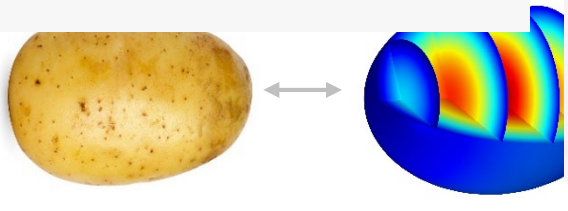


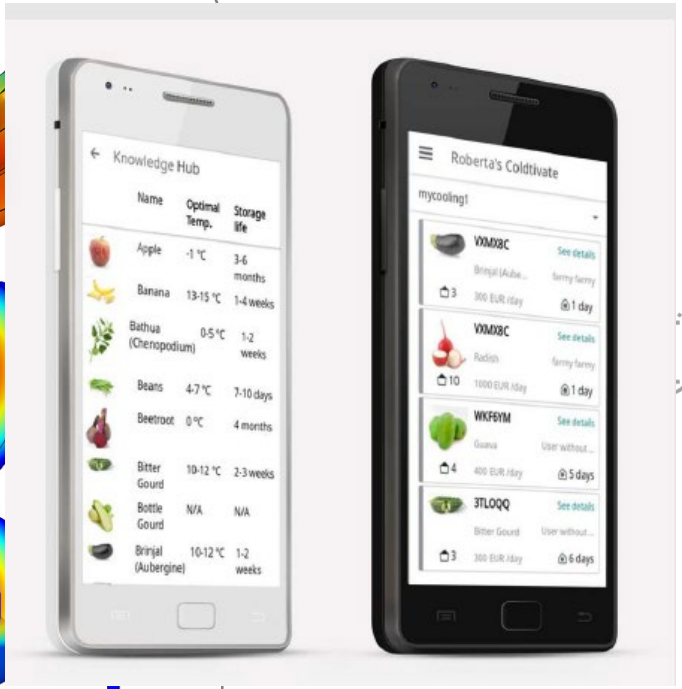
- Non-thermal → heat sensitive materials
- Faster drying with better quality
- Decentralized airflow production
- Energy consumption

Deploying these digital twins to our stakeholders?

Physics-based digital twins

Coldtivate™





https://yourvcca.org/
https://www.comsol.com/story/forecasting-fruit-freshness-with-simulation-apps-119431

BASE

Visit us for more info …

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COLDTIVATE APP:
MANAGING AND STEERING FRESH PRODUCE STORAGE OF SMALL-HOLDER FARMERS

1. DIGITALIZE AND OPTIMIZE COLD ROOM MANAGEMENT
2. FRUIT QUALITY PREDICTIONS TO PREVENT LOSSES
3. MARKET PRICE PREDICTIONS TO TELL OPTIMAL MARKETING TIME

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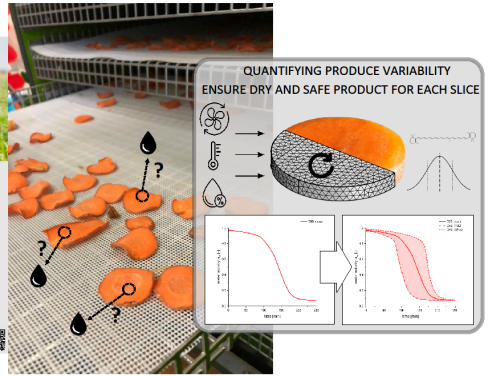
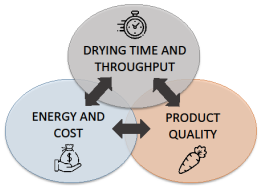
HYBRID DIGITAL TWINS: THE NEXT LEVEL
CONTROLLING INDUSTRIAL FOOD DRYING PROCESSES





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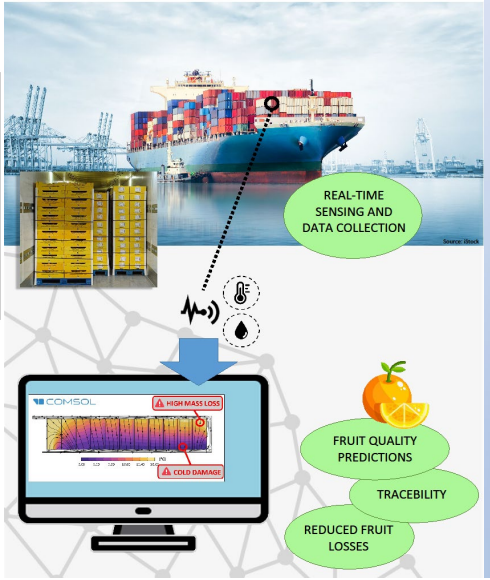
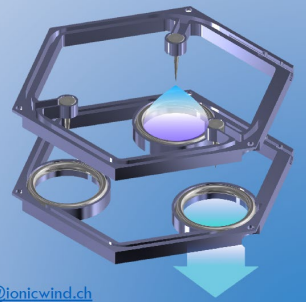
DIGITAL TWINS: REVOLUTIONIZING REFRIGERATED TRANSPORT



ionic wind
TECHNOLOGIES

NASA-inspired innovation
now for FoodTech, MedTech and ventilation

USPs
- precise airflow
- noiseless
- versatile
- low-energy
- solid-state
- disinfection



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The
ROCKEFELLER
FOUNDATION

World Food System
Center

Innosuisse - Swiss Innovation Agency
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

FNSNF

german
cooperation
DEUTSCHE ZUSAMMENARBEIT

giz

mastercard
Center
for Inclusive
Growth

coop

INDUSTRIE