Publication Series | 836C

Growing Greenhouse Tomatoes

Ministry of Agriculture,
Food and Agribusiness

Ontario

This guide is published for informational purposes only. The Province of Ontario, as represented by the Ontario Ministry of Agriculture, Food and Agribusiness (OMAFA), disclaims any expressed or implied warranties related to the use of this guide, including all contents, any link to or the contents of any third-party site or source, including, without limitation, warranties of non-infringement or of fitness for any particular purpose.

In no event shall the Province of Ontario or its directors, officers, employees, servants or agents accept any liability for any failure to keep the guide's contents up to date or for any errors or omissions within it or in any link or third party site or sources that may be referenced within it or for any damages (including, without limitation, damages for loss of profits, business interruption, loss of information or direct, indirect, incidental, special consequential or punitive damages), whatsoever arising out of or related to the use of or inability to use this guide (including all contents), any link or any third party site or works, whether under contract, in tort or under any other basis of liability. It is the user's responsibility to ensure they have chosen the best course of action for their own particular circumstances.

The contents of this guide (including, without limitation, the graphics, icons and its overall appearance) are the property of the Province of Ontario. The Province does not waive any of its proprietary rights therein including, but not limited to, copyrights, trademarks and other intellectual property rights.

No user of this guide may sell, republish, print, download, copy, reproduce, modify, upload, post, transmit or distribute in any way any portion of this guide or its contents without the prior written consent of the Province, except for reasonable printing, downloading and copying for the private information and use of the user. The availability of any of the contents of this guide shall under no circumstance constitute a transfer or waiver of any copyrights, trademarks or other intellectual property rights of the Province to any user or to any third party.

Published by the Ministry of Agriculture, Food and Agribusiness

Toronto, ON

ISBN 978-1-4868-9559-5 (Print)
ISBN 978-1-4868-9560-1 (PDF)

P836C-P1-0426-VER 1.0

Cette publication est aussi disponible en français.

Front Cover: A modern glass non-lit commercial greenhouse growing beefsteak tomatoes using a raised trough system in southwestern Ontario. This young crop was approximately four months old when the picture was taken in April, 2022.

Back Cover: A modern glass non-lit commercial greenhouse growing beefsteak tomatoes using a raised trough system in southwestern Ontario. This mature crop was approximately nine months old when the picture was taken in September, 2024.

To obtain a digital copy of this publication visit ontario.ca/crops and search for the publication number and title.

To order a print copy of this or any other OMAFA publication, visit ontario.ca/publications.

Agricultural Information Contact Centre
at 1-877-424-1300 (1-855-696-2811 (TTY)
or ag.info.OMAFA@ontario.ca

Publication Series | 836C

Growing Greenhouse

Tomatoes

Ministry of Agriculture,
Food and Agribusiness

Ontario

Publication 836 | Book C
Growing Greenhouse Tomatoes

Editor and Technical Writer
Dr. Fadi Al-Daoud, Greenhouse Vegetable Specialist, Ontario Ministry of Agriculture, Food and Agribusiness (OMAFA)

Technical Writing Contributors
Dr. Xiuming Hao, Senior Research Scientist, Agriculture and Agri-Food Canada (AAFC)

Technical Reviewers
The editor would like to thank industry partners and the following people for reviewing this publication:

Dr. Jason Lanoue, Research Scientist, AAFC
Kathryn Russell, Greenhouse Floriculture Specialist, OMAFA

Project Management/Art Direction
Dr. Nicole Berardi, Technology Transfer Specialist (OMAFA)
Andrea Vieira, Publications Officer (OMAFA)

Illustrations
Michael Custode

Acknowledgments
The editor would like to thank the following whose photos, text or data were used in creating this publication:

Agriculture and Agri-Food Canada's Harrow Research and Development Centre
Vineland Research and Innovation Centre

Information used in this guide has been compiled from a number of sources including Ontario Ministry of Agriculture, Food and Agribusiness technical publications.

This publication is the third in a series that will replace Publication 836: *Growing Greenhouse Vegetables, 2010*

Contents

List of Figures

List of Tables

Overview

This book is Part C of a series and replaces the tomato chapter of Publication 836: *Growing Greenhouse Vegetables*. Visit ontario.ca/crops for more information.

This publication provides an overview of key concepts for the production of greenhouse tomatoes in Ontario. This information is meant to be used as a guide for growers, and as part of the Greenhouse Vegetable Course. For timely updates and more information on the Greenhouse Vegetable Course visit the ONGreenhouseVegetables.ca blog.

Maximizing fruit yield in a greenhouse operation requires proper management and control of the growing environment to achieve optimal plant growth. Greenhouse production is considered a type of controlled environment agriculture (CEA) because many factors can be controlled in today's high technology greenhouses. The factors discussed in this book, including temperature, irrigation, relative humidity, carbon dioxide (CO_2) and lighting, are specific for greenhouse tomato production. This book also includes information for summer and winter tomato production, as well as sections dedicated to physiological disorders of greenhouse tomatoes.

Plant growth can be manipulated by controlling the environment of a greenhouse. However, it is recommended that a cost-benefit analysis be performed before implementing any changes to minimize input costs and waste while maximizing fruit yield and quality. For example, the costs and benefits of installing supplemental lighting must be weighed to ensure it is economically sustainable. This can be done by calculating and comparing the capital and operating costs versus the anticipated increases in production. Most greenhouse operators perform small-scale tests of new technologies in one section of their greenhouse before implementing it on a larger scale across their whole operation. Such tests should last for at least one growing season to collect enough data on input costs and yield and to be able to compare those numbers with previous seasons.

Crop Cycles

Traditionally, two short-season crops of greenhouse tomatoes are grown per year. Seedlings for the spring crop are typically grown in mid to late November, transplanted in late December or early January, with harvest beginning in mid to late March and crop termination in July. This is followed by a fall crop for which seedlings are grown in late June and transplanted in August, with harvest beginning in October and crop termination in November or December. To decrease downtime, intercropping is sometimes used where planting and harvesting are staggered to allow for mixing of spring and fall crops. (Table 1).

Recently, more producers are growing a single long-season crop. Seedlings for this crop are grown in early November, transplanted in late December or early January, with harvest beginning in mid to late March and a finished crop in October or November. This is known as a summer crop (Table 1).

These short-season spring and fall and long-season summer crop cycles have no or little production from November to February. This is when tomato prices are typically high because of weak market supply. Producing tomatoes from November to February (winter crop) can be accomplished using supplemental lighting (see Publication 836B, Chapter 9: *Supplemental Lighting for Winter Production*). Seedlings are typically grown in late July, transplanted in September or October, with harvest beginning in November or December and the crop is terminated in July or August (Table 1). To be successful, this requires a large capital investment, secured electrical rates and high marketplace returns.

Producers adjust the start and finish of the crop to suit market demand, while considering light availablility.

Table 1. Crop Cycles for Greenhouse Tomatoes

Crop Type	Seedling Propagation	Transplantation	Harvest Begins	Crop Termination
Short-Season Crops				
Spring Crop	mid to late November	late December or early January	mid to late March	July
Fall Crop	late June	August	October	November or December
Intercropping Short-Season Crops				
First Crop	mid to late November	late December or early January	mid to late March	July
Second Crop	late May or early June	July	September	November or December
Long-Season Crops				
Summer Crop	early November	late December or early January	late March	October or November
Winter Crop	late July	September or October	November or December	July or August

Cultivars

In the 1970s and 1980s the pink tomato was popular. This tomato was geared for a specific market and was resistant to Fusarium crown and root rot that afflicted the Ontario greenhouse sector in the 1970s. Consumer demand, as well as the transfer of disease resistance to red tomato cultivars, drove the shift to beefsteak tomatoes in the 1990s. Beefsteak tomato is a red tomato with a large fruit. The optimal fruit size is 200–250 g (28–34 fruit per 6.8 kg box). Changing consumer preferences in the 2000s have resulted in an increase in the production of tomatoes on the vine (TOV), also known as cluster tomatoes. This is a slightly smaller tomato than the beefsteak and is harvested on the truss/cluster and marketed as a bunch. Specialty tomatoes such as Roma, snack tomatoes such as cocktail and cherry tomatoes, and different coloured tomatoes (yellow, orange and brown) are grown for niche markets and increasing in popularity. There are several tomato cultivars of distinctive size, shape and colour that are suitable for the Ontario greenhouse sector. Consumer demand for high-quality, well-coloured and tasty tomatoes remains high.

Some characteristics to keep in mind are:

- yield and fruit size
- firmness and taste
- growth and plant habit
- calyx length
- abiotic (growing environment) and biotic (pest and disease) stress tolerance and resistance.

New cultivars released by seed companies should be tested on a small scale before being grown on a large scale.

Seedling Propagation

After purchasing seed of the cultivar of their choice, many producers send them to one of the greenhouse propagation facilities in Ontario dedicated to propagating fruits and vegetables. These propagation facilities germinate the seed and grow the seedlings for a few weeks before shipping them to the production greenhouse.

Some producers have greenhouse space dedicated to in-house propagation of seedlings. Typically, tomato seeds are sown directly into stone wool plug trays. Small operations sow seed by hand, while automatic seeders are used in larger operations. Before sowing, the plugs are soaked with plain water or a complete nutrient solution at an electrical conductivity (EC) of 1–1.5 mS/cm. EC measures water salinity and total dissolved salts or total ions present in a solution in milliSiemens per centimetre (mS/cm). The seeds are then covered with medium-grade vermiculite and the trays are placed in germination chambers maintained at 24˚C–25˚C and 100% relative humidity (RH). Alternatively, the trays are placed on germination benches with under-bench heat and covered with a 2 mm clear polyethylene sheet to maintain temperature and humidity.

Seed emergence occurs 2–3 days after sowing. After 60%–70% emergence, trays are removed from the germination chamber or the plastic film is removed from the trays on the germination bench. The temperature is typically maintained at 24˚C for 1 or 2 more days and then gradually lowered over 2 days to 19˚C–20˚C in both the day and night. After the cotyledon leaves have expanded, the seedlings are fertilized with a complete nutrient solution at an EC of 1.0 mS/cm, which is gradually increased as the plants develop.

After germination, seedlings are typically moved to a greenhouse with flood

floors (Figure 1). Seedlings benefit from supplemental lighting (18-hour photoperiod at 40 watts/m^2) and carbon dioxide (CO_2) levels of 800–1,000 parts per million (ppm) (to learn more about CO_2 enrichment, see Publication 836B, Chapter 5: *Carbon Dioxide*).

Figure 1. Seedling propagation greenhouse with flood floors.

The crop must get off to a good start to achieve successful tomato production. Healthy transplants with well-balanced growth can result in excellent production of high-quality fruit. Producers aim to strike a balance between vegetative and generative growth See Publication 836B, Chapter 1: *Vegetative or Generative Plants*.

An overly vegetative crop has:

- large leaf area
- delayed flowering
- poor fruit set
- smaller fruit
- delayed harvest
- higher susceptibility to disease

In contrast, a plant that is too generative has:

- high fruit load
- smaller leaves
- weaker growing points
- poor and delayed fruit set
- less yield

Use a pure source of CO_2 for seedling propagation because seedlings are extremely sensitive to harmful by-products of incomplete natural gas combustion.

Transplanting

If transplanting occurs too early or the plant growth is not controlled, the plant remains too vegetative. This results in delayed flowering and harvest, a tendency for smaller, misshapen fruit and a plant more prone to disease infection. On the other hand, a plant that is too generative results in strong flower production, a weak top, slower growth and delayed harvest. The objective at this stage is to strike a balance between generative and vegetative growth.

Since the early 2000s there has been an increase in the number of producers using grafted tomatoes to help combat root diseases and improve plant vigour, especially when growing a single long-season crop (for more information on grafting see Publication 836B, Chapter 11, *Plant Raising*). Controlling the early growth of the grafted plant by adjusting the greenhouse environment is important to produce a balanced plant and ensure early, high-quality tomatoes.

Transplanting typically begins 14–21 days after sowing or when the leaves touch the neighbouring plant. Seedlings are transplanted into 7.5 cm or 10 cm stone wool blocks with preformed holes to accommodate the plugs. The blocks are first soaked with a complete nutrient solution (pH 5.5, EC 1.5– 2.0 mS/cm). At each subsequent watering, the EC is gradually raised, eventually reaching 3.0–3.5 mS/cm at the time of transplanting. The rate of increase

is determined by the available light, rate of growth, plant vigour, available moisture and temperature regime (See Publication 836B: *Guide to Production of Greenhouse Fruits and Vegetables* for details about the interaction of these factors on plant growth).

Seedling plugs are placed into the hole of the stone wool block with the stem either straight or bent. Traditionally, bending the seedling places the cotyledon leaves and the growing point closer to the surface of the stone wool block. This allows for root development along the buried stem, providing greater plant stability. Producers today do not bend the seedlings because they use trellis string to support the weight of the growing plant.

Seedlings placed straight up in the hole must be staked. A thin bamboo stick is placed close to the seedling and elastic bands or metal rings hold the plants to the stake. The hole is sometimes covered with a layer of medium-grade vermiculite for added stability. The support of the stake allows the plant to grow bigger. This delays the need to tie the plants to overhead wires once transplanted in the production greenhouse.

The greenhouse temperature is maintained at 23˚C–25˚C for 1-2 days after transplanting seedlings to promote faster root establishment. Following this, the temperature is gradually lowered 1˚C/day to 19˚C (day and night). Supplemental light (18-hour photoperiod at 200 µmol/m^2/sec) and CO_2 levels of 800–1,000 ppm benefit the crop by producing compact transplants with strong roots, sturdier stems and earlier flower initiation.

Plant Raising

Early stages of tomato plant growth tend to be very vegetative. To ensure early, high-quality production, it is important to create greenhouse conditions that induce a more generative growth phase to encourage flower production (Figure 2). This can be managed by adjusting temperature, relative humidity, water and nutrition inputs in relation to the amount of available light. See Publication 836B: *Guide to Production of Greenhouse Fruits and Vegetables* for more details about the interaction of these factors on plant growth.

Figure 2. Greenhouse tomato flowers.

Plant Density

Tomato plant density can vary significantly from 2.5–3.5 plants/m^2 or more, depending on the cultivar, crop cycle and production system. The desired plant density can be achieved by adjusting plant spacing within the row. In stone wool culture, 2 plants/90 cm slab is recommended, with the bags spaced evenly within the row. Traditionally, plants are arranged in a twin-growing row 0.6–0.8 m apart, with a 0.9–1.2 m walkway separating the pairs of growing rows. Current practices are opting for a "V" system where plants have two main stems emerging from the same rootstock. This results in a single row with double the number of plants to achieve the desired plant density. The advantages of this widely used system include reduced input costs and labour savings; less growing media is used and less time is required to set up the greenhouse (Figure 3).

Figure 3. "V" system for tomatoes where two main stems are emerging from the same rootstock.

When light levels are higher during the summertime, plant density may be increased by allowing a side shoot to develop into a productive stem on every fifth plant or so. However, care must be taken because this tends to alter the relationship between plant, stone wool volume and water. When allowing more stems to develop, producers should monitor the irrigation frequency more closely because of the increase in water uptake. Mismanagement may result in smaller-sized fruit and increased disease incidence, especially when light levels drop. Developing and training an extra side shoot to increase stem density is normally initiated in March for a summer crop cycle.

Training

Plants are trained with a polypropylene twine for support. One end of the twine is loosely tied to the base of the plant with a small, non-slip loop, and the other end is attached to an overhead support wire. This overhead wire is 1.8–2.5 m above the plant row in traditional, shorter greenhouses and 3.0-3.5 m above the plant row in newer, taller greenhouses.

Proper tying of the twine at the base of the plant is important. If the knot is too tight, the plant may be damaged. If the knot is too loose, the plant may fall or slip down and snap the stem. In some cases, the twine can be placed between the bottom of the transplant block and the top of the stone wool slab, so the weight of the plant keeps the twine in place. However, problems can develop if the nutrient solution begins wicking up the twine. This damages the plant where the twine and stem are in contact, resulting in loss of production and creating potential sites for diseases such as Botrytis.

As the plant grows, it is twisted around the twine in 1-2 easy revolutions for each fruit cluster. Once the plants are larger and heavier (usually at the fourth or fifth cluster stage), plastic snap-on clips are used to attach the plants to the twine (Figure 4).

Figure 4. Training tomato plants to a high wire using clips to attach the plant to the twine.

For a spring crop, an additional 2.0–2.5 m of twine is draped over the top wire. As the plant reaches the wire, the twine is untied and the plant is lowered, allowing the lower section of the plant to lie on the ground or the wire support. This is called lowering. Overhead hooks, with a season's supply of twine stored on them, are also available and are commonly used in high-wire tomato production houses, making it easier to lower the crop.

Before lowering, it is important to remove the lower leaves to:

- improve bottom air circulation
- maintain an ideal environment at the base after the plant is lowered
- allow workers to find the fruit easily when harvesting

Leaf and Cluster Pruning

Maintaining an ideal leaf-to-fruit ratio is an important aspect of greenhouse tomato production. By removing leaves (deleafing), producers control the vegetative and generative balance. When leaves are removed, plants tend to grow more generatively, producing more fruit. If more leaves are left on plants, it promotes more vegetative growth and less fruit production. The amount of deleafing required is dependent on the cultivar being grown.

Greenhouse tomatoes are typically pruned once a week to remove all side shoots (suckers). Ideally, only 1-2 leaves are removed at a time, because removing too many leaves all at once alters the leaf-to-fruit ratio and reduces yield. In general, producers aim to have 18–20 leaves on a plant (roughly 1.2 m of leaf-bearing stem), especially in the summer months for a summer crop cycle. Early in the cropping cycle, 12–15 leaves are left on a plant to maintain fruit quality and rate of fruit development. Some cultivars may require aggressive deleafing. In this case, producers remove a leaf in the middle of the plant and another near the growing point when the plant is approximately at the third or fourth flowering truss stage. This may need to be repeated until plant vigour is controlled (especially a problem in fall crops).

Before termination of the crop at the end of the production cycle, producers pinch off or cut off the growing point of the plant. This is known as topping the crop, and it occurs about 6-8 weeks before harvest ends for a spring or summer crop and 8-10 weeks for a fall or winter crop. This transfers the sugars and energy normally used to produce new flowers and leaves to the fruit, causing them to enlarge and ripen faster.

As most modern tomato cultivars set fruit readily, all flowers on a truss may set fruit. The time between the setting of the first and the last flower may be 4–10 days, resulting in a range of fruit sizes at harvest time. To ensure uniform size and rapid harvest, producers prune each cluster to 4 fruits for beefsteak tomatoes or 5 fruits for TOV. Specialty tomato clusters are pruned to balance the plant and maintain fruit size and cluster quality. Once the desired flowers are properly set, the remainder of the flower trusses are pruned. Under good light conditions, or with a strong, vigorous beefsteak cultivar, it may be necessary to leave 5 fruits/cluster up to the third cluster and 4 fruits/cluster for subsequent clusters. This decision must be carefully considered because too much fruit load on the lower clusters severely restricts later production. Truss supports are usually necessary to prevent the fruit truss from kinking (Figure 5),

Figure 5. Example of truss supports used to prevent kinking of stalk.

Pollination

Pollination is necessary for normal fruit set. Tomato flowers are self-pollinating, which means they possess both male and female parts. But the pollen from the anthers must reach the ovaries at the base of the stigma for fertilization and fruit development to occur. The number of seeds that develop determines fruit size, quality and shape. To ensure high-quality, uniform tomatoes, producers often use bumblebees to increase pollination (Figure 6). On smaller farms, producers use vibrating devices such as electric bees or brushes.

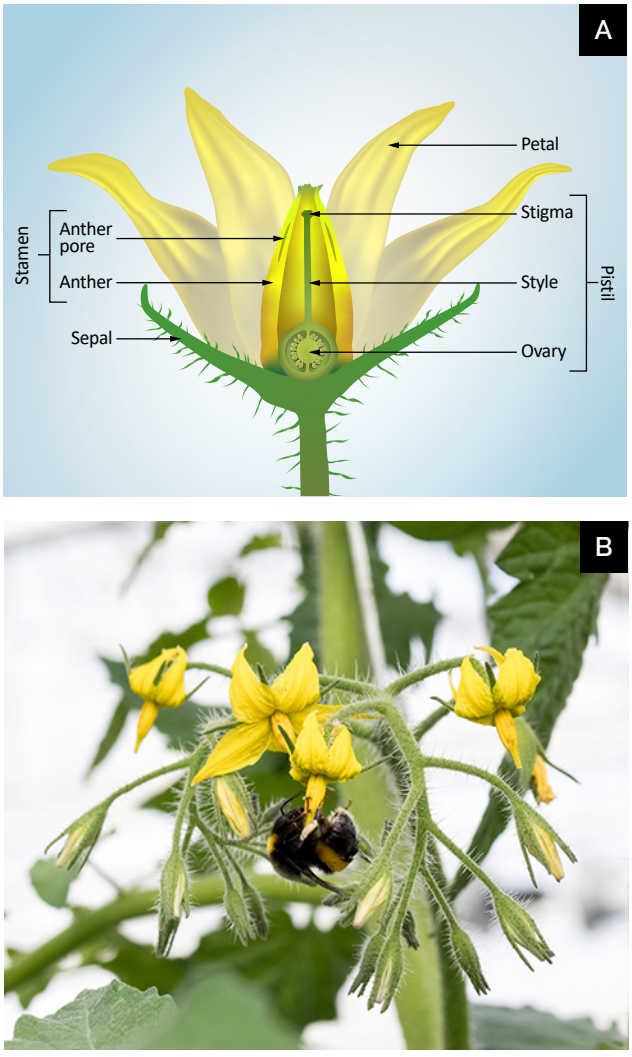

Figure 6. (A) Illustration of a cross section of a tomato flower. (B) Bumblebee visiting a tomato flower.

Successful pollination involves:

- production of viable pollen
- release of the pollen from the anthers to the stigma
- germination of the pollen grains on the stigma
- growth of the pollen tubes down the inside of the stigma, resulting in fertilization and subsequent fruit set

Note
Fruit with more seed present tend to be larger and better shaped.

Producers typically introduce 2-3 bumblebee hives per hectare (Figure 7) once the first flower cluster is fully opened. When bumblebee workers visit the flowers to obtain pollen, many pollen grains are dislodged from the anthers and land on the stigma to initiate pollination. The bumblebees visit flowers when pollen is available (mid-morning to early afternoon) and visit the same flower several times over the bloom period.

Figure 7. Bumblebee hives in a tomato greenhouse.

As the plant grows and more flowers open, producers add extra hives to achieve a total of 4-5 hives per hectare, or as recommended by the bumblebee supplier. This level is maintained for the duration of the growing season. As the hive ages, the worker bumblebee population declines and the social order of the hive changes, resulting in an inefficient hive. Hives lose their pollination efficiency after 6-8 weeks. When this occurs, producers replace the hives or bring in more hives to maintain good pollination. This is repeated throughout the growing season.

Hives should be placed in a convenient location on a sturdy stand or shelf located 1.0–1.5 m off the ground. If the area is unshaded, provide a shade cover to prevent overheating in the summer. Hives should also be placed away from vibration or drafts. Hives placed in a cool location are slower to develop enough adult worker bumblebees to efficiently pollinate the crop.

Modern hives are designed to provide a carbohydrate source for the bumblebees, requiring little or no maintenance by the operator. Hives are also equipped with a one-way opening that can be activated to allow the bumblebees to enter the hive but not exit it. This is necessary to capture all the bumblebees when the hives are being removed.

A brown discoloration or marking of the flower's cone/trumpet indicates that a bumblebee has visited the flower. Producers monitor these marks to determine bumblebee performance (Figure 8).

Bumblebees are sensitive to various chemicals and pesticides. Once chemicals are introduced into the hives, they cause the hive to deteriorate, resulting in poor pollination. A good biological control program against pests is necessary to reduce pesticide application and obtain the full benefit of bumblebee pollination.

Figure 8. Good pollination indicated by brown marks on a tomato flower caused by bumblebee visits.

While bumblebees will exit greenhouses through vents, they usually return. However, if the outside temperature is low or the vents close before the bumblebees return, they will die, especially in February and March. Bumblebees are sensitive to light in the ultraviolet (UV) spectrum. They use it to orient themselves during foraging. If the greenhouse covering does not allow adequate UV light inside the greenhouse, then the bumblebees are more likely to escape.

To prevent bumblebees from escaping the greenhouse:

- change the poly covering to provide a better light environment for bumblebees
- decrease the size of the vent opening and compensate by installing end-wall fans to assist in early venting
- install bee screens at the gutter vent to prevent escapes

In small tomato greenhouses, bumblebee pollination may not be ideal because the demand for pollen can be high in a typical bumblebee hive that has as many as 300 adult bees. High demand for pollen may result in excessive visits to each flower,

which can cause damage (Figure 9) and flower abortion in extreme cases.

Figure 9. Tomato flower damaged by too many bumblebee visits as indicated by shriveling and excessive browning.

To prevent damage, flowers can be hand-pollinated using electric bees to gently vibrate the flowers. Backpack air blowers, similar to leaf blowers, can also be used to pollinate the flowers. Other methods, such as tapping the overhead wires or the string supporting the plants, or using coarse water sprays, have not generally been effective.

Adverse temperatures, light and nutritional conditions can compromise the pollination process and result in poor fruit set and fruit quality. The day temperature should not fall below 18˚C or exceed 30˚C once flowering starts. During late fall, winter and early spring, most cultivars produce flowers with a slightly different shape, making natural pollination more difficult. This is a result of low light and temperature and is occasionally aggravated by high nitrogen levels. The optimum time for pollination is between 11 a.m. and 3 p.m., when flowers are dry and pollen is shedding. Inadequate pollination results in poor and uneven seed set, which causes hollow, misshapen, poor-quality fruit.

Temperature

Air temperature has a profound effect on plant growth, flower development and quality of fruit. The 24-hour average temperature affects the rate of growth: the higher the 24-hour average temperature, the faster the growth. A tomato crop achieves maximum growth when both day and night temperatures are 25˚C. On the other hand, maximum fruit production is achieved when temperatures are 20˚C during the day and 18˚C during the night or when the 24-hour average is 19˚C. The temperature difference between day and night determines the shape of the plant and the degree of vegetative versus generative growth.

Producers adjust temperatures based on available light and CO_2 levels to maintain high growth rates and produce large, good-quality fruit (Table 2). Under lower light conditions (early winter or cloudy days), producers maintain a lower 24-hour average temperature and then increase it when the light level increases. The day-night temperature difference can be adjusted to maintain plant vigour and fruit size. A large day-night temperature difference shifts the plant to a more generative phase (more flowers, thinner heads, larger fruit size), while little or no temperature difference results in a more vegetative plant (fewer flowers, thicker heads).

Table 2. Recommended Air Temperatures (°C) for Tomatoes with Different Levels of Light and CO_2 Enrichment

Temperature Scenario	Low Light (cloudy days)	High Light (sunny days)	With CO_2 Enrichment
Night minimum (°C)	17	18	18
Day minimum (°C)	19	21	21
Ventilation temperature (°C)	21	24	26

Higher temperatures are usually maintained when CO_2 enrichment is used during the day to maximize photosynthesis. However, CO_2 enrichment reduces the ability of plants to cool themselves because their stomata are not as open as they are under lower CO_2 levels. Therefore, be careful if enriching with CO_2 under hot conditions (for more information on CO_2 enrichment and its interaction with temperature and light see Publication 836B, Chapter 5: *Carbon Dioxide*).

Note
During very sunny weather, temperatures higher than 26°C will not harm the plants, but above 29°C the blossoms will be injured on most cultivars.

Note
For growing media, a minimum temperature of 16°C is recommended. The optimum is 18–21°C.

Light

Light is also a critical component of tomato production. Under low light conditions in winter, plants tend to have long internodes, reduced flower bud development and clusters that fail to set fruit. These problems are minimized by decreasing the rate of growth through one or more of the following production practices:

- lowering the 24-hour average temperature
- lowering the volume of water applied
- raising the EC of the nutrient solution and the root zone media
- lowering the relative humidity (RH) (raising the vapour pressure deficit (VPD))
- increasing air movement within the crop

Supplemental lighting is needed for winter production of tomatoes. For more information on supplemental lighting for winter production, see Publication 836B, Chapter 9: *Supplemental Lighting for Winter Production*.

In the summer, when light levels are high, using a shade screen specific for vegetable crops or applying whitewash or other coatings to the exterior of the greenhouse reduces both the light intensity and temperature inside the greenhouse (for more information on light transmission and distribution see Publication 836B, Chapter 3: *Light*). This results in a stronger head, improves flower quality and fruit set and decreases fruit quality problems associated with a high fruit temperature.

Relative Humidity (RH)

The tomato crop can withstand a wide range of RH levels as long as it does not fluctuate drastically over a short period. Ideally, producers keep RH at 75%–85% or VPD at 0.4–0.8 kPa. When the VPD is high (low RH), water supply to the crop is critical to maintain good fruit set. A low VPD (high RH) can improve fruit setting during the day, but also increase the incidence of diseases.

Adjusting the VPD will also alter plant vigour and appearance. For example, under high VPD, the plant tends to have a thinner head and leaves. At lower VPD, the plant tends to have thicker leaves and heads, as well as flowers with extended fruit trusses that are more prone to kinking or bending, resulting in poor fruit size and shape (for more information on RH, VPD, and their relationship with leaf temperature see Publication 836B, Chapter 4: *Relative Humidity*).

Carbon Dioxide (CO_2)

CO_2 enrichment benefits the tomato crop at all stages. During sunny days, producers usually use 1,000 ppm of CO_2, but reduce it to 400 ppm if the vents are opened more

than 10%. Under low light conditions on cloudy days, CO_2 levels are kept at 400 ppm. In the summer, when ventilation is used, it is economical and increasingly popular to apply supplemental CO_2 at concentrations up to 400 ppm, especially early in the day. As noted in the Temperature section above, CO_2 enrichment reduces the ability of plants to cool themselves in hot conditions (for more information on CO_2 enrichment and its interaction with temperature and light see Publication 836B, Chapter 5: *Carbon Dioxide*).

Air Flow

Air flow helps minimize temperature gradients in the greenhouse and uniformly distributes CO_2 throughout the canopy. An air speed of 1 m/second is recommended. There are different models of greenhouse fans to consider. Horizontal, vertical and through-curtain fans are the three main types (Figure 10). Horizontal and vertical fans can reduce the horizontal and vertical heat gradients in a greenhouse, depending on their height and orientation. Through-curtain fans are advantageous because they mix the air from above and below the curtains, when curtains are 100% closed, reducing temperature variations between those areas. This also reduces the need for growers to gap their curtains to ventilate the greenhouse. Gapping curtains reduces their efficacy and increases temperature gradients in greenhouses.

Figure 10. (A) Traditional horizontal fans on the side of a low tomato greenhouse. (B) Modern horizontal fan above a tomato crop in a tall greenhouse. (C) Modern through-curtain fan.

Water and Nutrition

Sustained fruit production requires optimum environmental conditions and timely applications of water and nutrients. Regulating the supply of water and/or nitrogen are the most common and effective techniques used to control crop growth.

A well-balanced plant is characterized by its thick stem, dark-green leaves and large, closely spaced, easy-setting flowers. A properly nourished plant has a stem that is 1 cm thick at 15 cm below the growing tip. Thicker stems indicate excessive vegetative growth and are usually associated with poor fruit set and low productivity. Thinner stems usually indicate carbohydrate starvation, slow growth and ultimately low overall productivity.

A mature tomato crop uses 2-3 L of water per plant per day when light levels are high (on an average summer day, for example). Infrequent and low volumes of irrigation, low RH and high EC can all result in plants that are too generative and slow growing. However, too much growth is also undesirable. The preferred method to slow growth is by regulating EC and the amount and frequency of watering, as it is simple, effective and dependable.

A complete nutrient solution must be applied at all times to sustain the growth and fruit development necessary to obtain high production of good-quality tomatoes. Adjust the fertilizer schedule based on the stage of the crop (Table 3) (Table 4).

The rate at which tomato plants absorb nutrients varies at different stages of growth. This is especially true for nitrogen and potassium. When tomato plants have 2-3 flower trusses, they absorb nitrogen at about the same rate as potassium. As the fruit load increases, so does the potassium uptake, resulting in a 2:1 ratio of potassium to nitrogen uptake.

Lower nitrogen feed levels during this phase help control plant growth (Table 5).

Too much nitrogen under low light conditions early in the production cycle results in:

- an overly vegetative plant prone to disease
- poor flower development
- poor fruit set
- small fruit size

Nitrogen supply can be regulated directly by adjusting the nitrogen fertilization or indirectly by varying the supply of other nutrients, such as potassium. Increasing the potassium:nitrogen ratio in the fertilizer solution is a technique frequently used to slow growth.

The volume and timing of the nutrient solution applied through fertigation is critical for tomato plants grown in stone wool and coco coir media and greatly affects fruit quality. Producers usually begin fertigation 1-2 hours after sunrise and end it 1-2 hours before sunset. This helps decrease the incidence of russeting and fruit cracking in the summer, as well as diseases. Night watering may be needed during the winter months when heating systems are fully operational and the RH in the greenhouse is low or during the summer when light intensity and day temperatures in the greenhouse are high.

Note
Other factors can also strongly influence plant growth and must be considered together. For details, see Publication 836B: *Guide to Production of Greenhouse Fruits and Vegetables*.

Note
For more information on nutrients see Publication 836B, Chapter 12: Nutrients and Analytic Testing, and for information on symptoms of deficiency and toxicity see the Physiological Disorders section below.

Table 3. Fertigation Schedule for Tomato (ppm nutrient)

Growth Stage	N	NH_4	P	K	Ca	Mg	Fe	Mn	Zn	B	Cu	Mo	S*	Cl*	HCO_3
A. Slab saturation	200	10	50	353	247	75	0.8	0.55	0.33	0.5	0.05	0.05	120–200	100–125	25
B. 4–6 weeks after planting	180	10	50	400	190	75	0.8	0.55	0.33	0.5	0.05	0.05	120–200	100–125	25
C. Normal feed	190	22	50	400	190	65	0.8	0.55	0.33	0.5	0.05	0.05	120–200	100–125	25
D. Heavy fruit load	210	22	50	420	190	75	0.8	0.55	0.33	0.5	0.05	0.05	120–200	100–125	25

** The fertilizers selected to create the nutrient solution will determine the final level of these elements.*
Notes: Based on research conducted at the Harrow Research and Development Centre, Harrow, and at the Vineland Research Station, Vineland Station.
Refer to Nutrient Abbreviations table in Appendix C for full names of nutrients.

Table 4. Weights of Fertilizer Required to Make Stock Nutrient Solutions

Fertilizer	A*	B*	C*	D*
Kg/1,000 L (Dilution ratio 1:100)				
Calcium nitrate	112	82.1	82.1	82.1
Potassium nitrate	25.72	42.4	40.89	56.27
Monopotassium phosphate	6.75	6.75	6.75	6.75
Potassium sulphate	45.11	38.08	39.21	31.81
Potassium chloride	3.75	3.75	3.75	3.75
Magnesium sulphate	66.0	66.0	56.0	66.0
Ammonium nitrate	0.0	4.0	8.0	8.0
Fertilizer	**A***	**B***	**C***	**D***
G/1,000 L (Dilution 1:100)				
Iron chelate, 13%	615.38	615.38	615.38	615.38
Manganese sulphate	207.69	207.69	207.69	207.69
Zinc sulphate	94.29	94.29	94.29	94.29
Borax	326.67	326.67	326.67	326.67
Copper sulphate	16.0	16.0	16.0	16.0
Sodium molybdate	10.87	10.87	10.87	10.87
Desired EC (mS/cm)	2.5–3.0	3.5	3.0–4.0	2.5–3.5
Desired pH	5.8	5.8	5.8	5.8
Volume of water (L)**	0.25–0.5	0.5–1.0	1.0–2.0	1.5–2.5

** See Table 3, Fertigation Schedule for Tomato for an explanation of these codes.*
*** As required, based on watering strategy.*
Note: Based on research conducted at the Harrow Research and Development Centre, Harrow, and at the Vineland Research Station, Vineland Station.

Table 5. Summary of Growing Recommendations for Tomatoes

Temperature and Fertigation	Germination	Plant Raising	Transplanting	Harvesting Stage	Full Harvest
Day temperature (°C)*	25	19–21	24	19	20–22
Night temperature (°C)*	25	19–21	24	19	17–19
Solution EC (mS/cm)	0.0–1.0	2.5–3.0	2.5–3.0	2.7–3.5	2.7–4.0
Solution pH	5.8	5.8	5.8	5.8	5.8
Volume of nutrient solution (L/day)**	—	0.2–0.3	0.2–0.3	0.5–1.5	1.5–2.5
Fertilizer schedule***	—	A	B	C	D

** Use lower settings when light level is low.*
*** As required based on watering strategy.*
**** See Table 3, Fertigation Schedule for Tomato, for an explanation of these codes.*
Note: Based on research conducted at the Harrow Research and Development Centre, Harrow, and at the Vineland Research Station, Vineland Station.

Harvesting and Storage

Producers typically harvest greenhouse tomato fruit with the calyx attached to help identify the product. Tomatoes are typically harvested 3 times/week or every other day, especially during the summer, to ensure all fruit is picked at about the same stage of ripeness. Tomatoes are harvested when the fruit is turning from green to orange-red in colour. Some producers may harvest at the breaker stage (when the blossom end of the fruit is starting to show colour). Tomato fruit harvested at a more advanced stage of ripening has greater flavour but may have a shorter shelf life since it becomes over-ripe sooner.

Harvesting can be done manually by snapping or breaking the calyx at the knuckle (a natural break point on the flower stem). Cluster tomatoes can be cut close to the stem using a knife or scissors. The fruit is typically placed in picking baskets or crates to prevent the calyx from puncturing neighbouring fruit. If necessary, the stem is clipped to minimize punctures when the fruit is handled during packing and at display counters. Fruit that is dropped will easily bruise, shortening its shelf life.

Tomatoes are typically picked as early as possible in the morning while it is still cool. The fruit is moved to a covered area or directly to a cooler as quickly as possible because fruit left in the greenhouse rapidly overheats and deteriorates. The packing facilities must be cooled (15˚C) to maintain fruit quality. Pack uniformity (colour, size and quality) is critical to ensure good acceptance at the marketplace. Computerized colour sorters with weight and size grading, packing lines and automatic labellers are commonly used to pack tomatoes.

If required, store fruit at 12˚C after grading and packing. After removing the fruit from cold storage, take care to avoid condensation on the skin by moving it into a dry atmosphere or raising the temperature gradually. Use cooled trucks to ship the fruit to the marketplace.

Physiological Disorders

Physiological disorders in tomatoes are conditions that affect plant growth, fruit development and overall yield. Unlike diseases caused by pathogens, these disorders are a result of environmental stress and nutrient imbalances. Table 6 outlines common issues that can significantly reduce quality and profitability. Understanding the symptoms and causes for these disorders is essential for maintaining healthy tomato crops and ensuring consistent production.

Table 6. Tomato Physiological Disorders

Disorder	Symptoms	Causes
Blocky Fruit*		
	Misshapen fruit that is more square or blocky.	• low temperatures • nutrient imbalances
Blossom End Rot (BER) For more information refer to section *Blossom End Rot (BER)*		
	Commonly seen as a firm, dry, sunken and discoloured area (brown or black) at or near the blossom end of the fruit (away from the stem). It can range from less than 0.5 cm in diameter to an area affecting more than half the fruit.	• lack of calcium (Ca) movement to the blossom end of the fruit • lack of calcium supply in the feed or the growing media • high electrical conductivity (EC) of the fertigation inhibits water uptake • excessive vegetative growth moves majority of calcium to the leaves • excessive transpiration through leaves due to high vapour pressure deficit (VPD) or low relative humidity (RH) • a dramatic change in fruit growth, resulting in higher calcium demand • unhealthy root system

** Photo source available in References.*

continued ››

Table 6. Tomato Physiological Disorders *(continued)*

Disorder	Symptoms	Causes
Catface*		
	Misshapen fruit with irregular protuberances at the blossom end. Streaks and bands of dark greenish, scaly scar tissue and crevices may be present at the blossom end or at the sides of the fruit.	• air temperature is too low for normal fruit setting • extreme temperature fluctuations between day and night • excessive nitrogen levels in the fertigation
Cracking or Russeting For more information refer to the section *Effects of High Temperatures on Greenhouse Tomato Fruit Development*		
	Minute hair-like cracks on the shoulders of tomato fruit. In mild cases, the cracks are visible under indirect light. In severe cases, they are readily visible. Russeting can be seen on immature green fruit, as well as on mature ripe fruit.	• fruit expanding faster than the skin can expand • genetics of the cultivar
Goldspot* For more information refer to section *Effects of High Temperatures on Greenhouse Tomato Fruit Development*		
	Yellow specks and flecks around the calyx and shoulders of mature fruit during summer production. Before tomatoes are mature these specks appear white in colour and are less abundant in green fruit.	• excess levels of calcium in the fruit, in contrast to BER • greenhouse environment that does not promote transpiration through the leaves, such as high RH • genetics of the cultivar
Green Shoulder For more information refer to section *Effects of High Temperatures on Greenhouse Tomato Fruit Development*		
	Uneven ripening where certain areas on the tomato surface remain green or yellowish-green while other areas develop to their normal colour.	• low EC levels of the fertigation • inadequate potassium • overcrowding • excessive fruit surface temperature • genetics of the cultivar • unhealthy root system

** Photo source available in References.*

‹‹ previous continued ››

Table 6. Tomato Physiological Disorders *(continued)*

Disorder	Symptoms	Causes
Pointed Fruit		
	Misshapen fruit with a pointed or elongated tip.	• high temperatures • poor pollination • genetics of the cultivar
Puffiness or Hollowness*		
	Fruit with large internal cavities and reduced number of seeds. Usually, only 1–2 tomatoes on an individual truss may be affected. Fruit on subsequent clusters may not be affected if environmental conditions improve.	• high or low temperatures during fruit development • nutrient imbalance with low potassium or high nitrogen levels • inadequate pollination • inconsistent fertigation
Sunscald* For more information refer to section *Effects of High Temperatures on Greenhouse Tomato Fruit Development*		
	Yellow patches on the side of the tomato fruit. Similar to green shoulder, the texture of affected areas is leathery and firmer than the surrounding tissues. Also, these yellow areas sometimes have a mottled appearance, and the surface is depressed.	• environmental factors, like exposure of the fruit to direct sunlight with no shade • not influenced by the genetics of the cultivar, unlike green shoulder

** Photo source available in References.*

« previous

Blossom End Rot (BER)

Blossom end rot (BER) is one of the most common physiological disorders that affects greenhouse tomatoes and one of the most studied. It is a localized disorder characterized by deterioration of fruit cell membranes, resulting in leakage of cell liquids. Typical symptoms appear 2-4 weeks after flowering, when the fruit is in rapid expansion. It is characterized by a large water-soaked dark spot on the blossom end of the fruit — away from the stem (Table 6). BER might develop internally in the tomato fruit without any external manifestations, causing black seeds or black pulp. It can also cause up to 50% yield losses in some circumstances. Many factors contribute to BER (Figure 11), including:

- physiology
- genetics
- abiotic stress
- agronomic practices

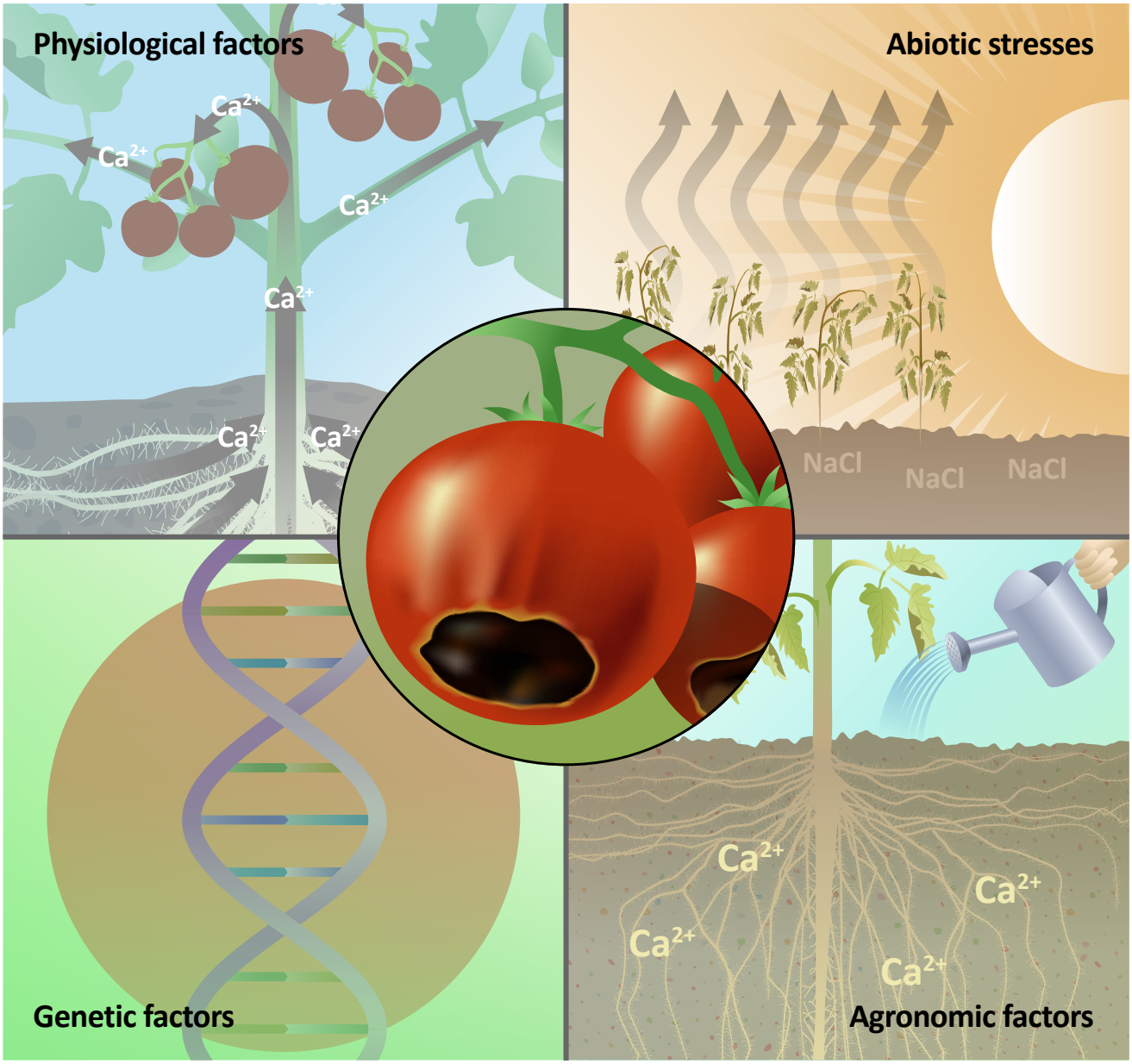

Figure 11. BER can be caused by many factors, including physiology, genetics, abiotic stress and agronomic practices.

Physiology

BER is primarily associated with local calcium (Ca) deficiency in fruit tissue. Calcium is critical for cell wall stabilization and integrity, and plays a key role in promoting shelf life. Calcium is an immobile element. That means that unlike other elements that move in the phloem, its movement depends on transpirational water flow in the xylem. This results in more calcium being directed towards leaves rather than fruit because of their higher rate of transpiration (for more information about mobile and immobile nutrients, refer to Publication 836B, Chapter 12: *Nutrients and Analytic Testing*.

Not only does water flow regulate calcium, but calcium also regulates water flow in plants. Calcium regulates water movement on the outside of cells through changes in cell wall structure and stomatal openings, and it regulates water flow into cells via membrane channels called aquaporins. So it is a feedback loop where a reduction in transpiration reduces water and calcium movement into cells and the reduction in calcium reduces water flow even further, leading to even lower calcium levels.

When calcium enters the fruit tissue, it accumulates in the area close to the stem, which leads to low calcium levels in the blossom end (Figure 12). This gradient of calcium in the fruit greatly affects fruit development, especially during rapid cell expansion when the fruit is growing. Insufficient uptake and movement of calcium to the blossom end of the fruit at the early stages of fruit development and when the fruit is rapidly growing can lead to BER. A study by Aslani et al. (2020) reported that when calcium decreases below 0.2 µmol/g (or 0.2%) fresh weight in the blossom end of immature fruits, the risk of BER occurrence becomes critical.

Calcium shortage is not the only factor that can lead to BER. The availability of calcium in the growing media does not always correlate with BER and some fruits exhibiting BER have similar levels and distribution of calcium compared to healthy fruit. More complex mechanisms may lead to BER in tomato fruit, like oxidative stress. Oxidative stress occurs when an abiotic stress (like heat or drought) causes a build-up of reactive oxygen species (ROS). This build-up of ROS can lead to damage of lipids, proteins and DNA — key building blocks of cells. This typical cell stress response can lead to leakiness of the cell membrane, resulting in BER symptoms.

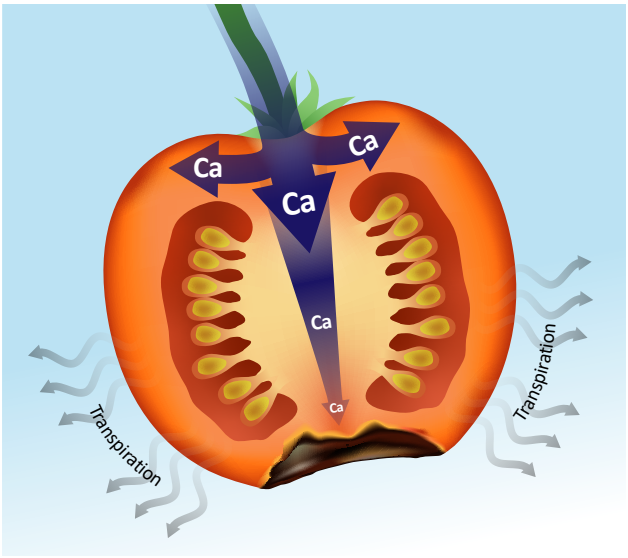

Figure 12. Calcium (Ca) gradient in tomatoes.

Oxidative stress is also linked to lower calcium levels. When oxidative stress occurs in the fruit it can lead to a reduction of calcium levels. Low calcium levels caused by oxidative stress also reduces the activity of antioxidants that detoxify ROS, leading to higher ROS levels and more cell damage and BER symptoms. This is another BER feedback loop where oxidative stress decreases calcium levels, and low calcium levels reduce the activity of antioxidants, which increases oxidative stress levels even more.

Genetics

BER is more prevalent in large tomatoes, such as beefsteak, rather than smaller tomatoes, like cherry tomatoes. This is known as the "fruit shape effect." BER is generally associated with large and mostly plum fruits, where the rapid expansion of cells could lead to inadequate movement of calcium. Interestingly, BER symptoms have never been reported in wild tomato species. This is thought to be another example of the fruit shape effect because wild tomatoes are typically smaller in size than cultivated tomatoes.

BER-resistant tomatoes have higher fruit antioxidant capacity, which makes them better at managing oxidative stress and its damaging effects on cell membranes. Some BER-resistant varieties have fewer leaf stomata, which leads to lower transpiration rates and more water flow into the fruit.

Abiotic Stress

Stress conditions such as heat, drought, water logging salinity and low root zone humidity increase the concentration of oxidative stress in young fruits. This causes leakiness of cells and lower calcium levels. High temperatures and solar radiation also induce higher rates of photosynthesis and transpiration in leaves, which cause more water and calcium to be directed towards leaves rather than fruits. These factors promote BER during high-stress conditions.

Agronomic Practices

Foliar Sprays

A common way of controlling BER is by spraying the fruit with calcium solutions (0.3%–0.5% solution of calcium chloride or calcium nitrogen, or 2–7 g/L calcium nitrate) to increase calcium levels in the fruit. However, these sprays are labour-intensive because only the fruit should be sprayed, not the whole plant. Spraying leaves is inefficient because calcium absorbed by leaves is not translocated to the fruits.

A number of plant hormones have been shown to reduce BER when sprayed on the plant. For example, a study by Riboldi et al. (2019) showed that epibrassinolide (EBL) reduced BER by 44.2%. Spraying EBL led to a reduction of leaf transpiration, higher calcium levels in the distal portions of the fruit and increased activity of antioxidants. A study by Barickman et al. (2019) showed that weekly foliar sprays or root application of the plant hormone abscisic acid (ABA) increased calcium levels in distal fruit tissue reducing BER. In contrast, other plant hormones, such as gibberellin (GA), can reduce fruit calcium uptake, leading to leakier cells and increasing BER incidence. Gibberellin increases the number of leaf stomata, which increases leaf transpiration rate and calcium transport to leaves at the expense of the fruit.

Pruning

Controlling plant density and truss thinning have historically been practiced to regulate tomato fruit size and reduce BER incidence. A study by Aslani et al. (2020) looked at how pruning to 1 fruit/truss, 2 fruit/truss, 3 fruit/truss or no fruit pruning affected the incidence of BER. The results showed that more fruits/truss had lower BER incidence. This was attributed to the slowing down of fruit growth by keeping more fruits/truss, which ensured adequate uptake and distribution of calcium. A study by Indeche et al. (2020) demonstrated that deleafing increased calcium levels in distal portions of tomatoes which lowered the risk of developing BER. The authors hypothesized that the reduced competition for water between leaves and fruits allowed sufficient calcium to be transported into the fruits at a critical time before BER was triggered.

Nutrient Balance

Sodium (Na), potassium (K) and magnesium (Mg) can decrease calcium uptake and

distribution which may increase BER. For example, if levels of sodium, potassium and magnesium in the nutrient solution are above 500, 400 and 80 mg/L, respectively, calcium uptake in tomatoes may decrease. A study by Hao and Papadopoulos (2004a) showed that the incidence of BER in tomatoes increased with increasing magnesium concentrations (20, 50, and 80 mg/L) when the level of calcium was 150 mg/L. However, BER incidence did not increase with higher magnesium concentrations if the calcium concentration was raised to 300 mg/L. This means that if calcium levels are high enough in the fertigation, then increasing magnesium levels may not promote BER development.

A study by Hernandez-Perez et al. (2019) observed, higher tomato yields when the potassium:calcium ratio was 0.82–0.85 in summer months. However, more calcium demand and a lower potassium:calcium ratio (~0.67) may be necessary in the autumn-winter season because lower temperatures and higher relative humidity reduce transpiration rates and calcium transport.

Growing Media

The growing media can also influence BER. A study by Marten et al. (2020) compared tomato seedlings grown hydroponically in peat, perlite and a 1:1 mixture of peat-perlite before being transplanted into stone wool slabs. Plants grown in perlite were smaller than those grown in the other media, most likely due to perlite's inability to retain nutrients. This did not result in significant losses in total yield and weekly yield of marketable fruit, but it did reduce BER levels. The reduction in BER incidence in the smaller plants is thought to be at least partially related to the smaller size of their leaves and their lower transpiration rate.

Conclusions and Recommendations

Some key things producers should keep in mind to reduce their risk of BER include the following:

1

Reduce Water Stress: Precisely and quickly match the irrigation with sunlight conditions.

2

Reduce Heat Stress: Apply whitewash to the greenhouses and/or use shade curtains to reduce high solar radiation and its associated high temperature stress. Some new energy curtains have light transmission between 85%–89% which can also be used in the summer as shade curtains. Also, try to reduce nighttime temperatures to promote fruit setting in the summer. High nighttime temperatures and high humidity reduce the viability of pollen in the summer, causing poor fruit setting. Poor fruit setting in combination with elevated rates of photosynthesis in high temperatures increases BER.

3

Reduce Nutrient Deficiency: Test your fertigation solution and plants regularly for nutrient deficiency to ensure plants are taking up enough calcium. Reduce the EC in irrigation in late afternoon to promote calcium transport during the night. Lower EC can promote higher turgor pressure by a healthy root system and send more calcium to the fruit because water flow is not driven by transpiration during the night.

Effects of High Temperatures on Greenhouse Tomato Fruit Development

During the summer, temperatures in Ontario vegetable greenhouses can surpass 30˚C for multiple consecutive days. Understanding how high temperatures affect the growth and development of greenhouse crops is an important first step in learning how to grow vegetables in hot greenhouse conditions. This section summarizes what is known about

the relationship between high temperatures and tomato fruit development in hydroponic greenhouse production.

A number of heat-related physiological disorders are discussed, including fruit cracking, green shoulder, sunscald and goldspot.

Tomato Fruit Development and Maturation

Development of the tomato fruit can be divided into three main stages (Figure 13):

1. **Stage 1** is characterized by cell division that occurs within 10 days after pollination.
2. **Stage 2** is between 10 and 40 days after pollination when cells grow and expand.
3. **Stage 3** includes ripening and maturation of the fruit after it has reached its final size.

Dramatic metabolic changes occur as the tomato fruit develops from a green organ, which is able to undergo photosynthesis, to a red fruit that is full of sugars, organic acids, vitamins A, B and C, lycopene and potassium. These compounds accumulate in the fruit at different stages of development. For example, during stage 2 and in the early phases of stage 3, organic acids and starch accumulate, whereas during the final stages of ripening in stage 3 organic acid and starch levels drop and sugar and lycopene levels increase.

The colour change that occurs during late maturation is partly the result of the chloroplasts in the cells (which give the fruit its green colour and are responsible for photosynthesis) changing into chromoplasts (which store carotenoids, including lycopene, that give the fruit its red colour). Maturation of the tomato fruit is influenced by a number of plant hormones, including ethylene, auxin, abscisic acid and brassinosteroids. Some of these plant hormones promote fruit ripening (ethylene, abscisic acid and brassinosteroids) while others inhibit it (auxin). Hormone levels also change with fruit development. Stage 1 is

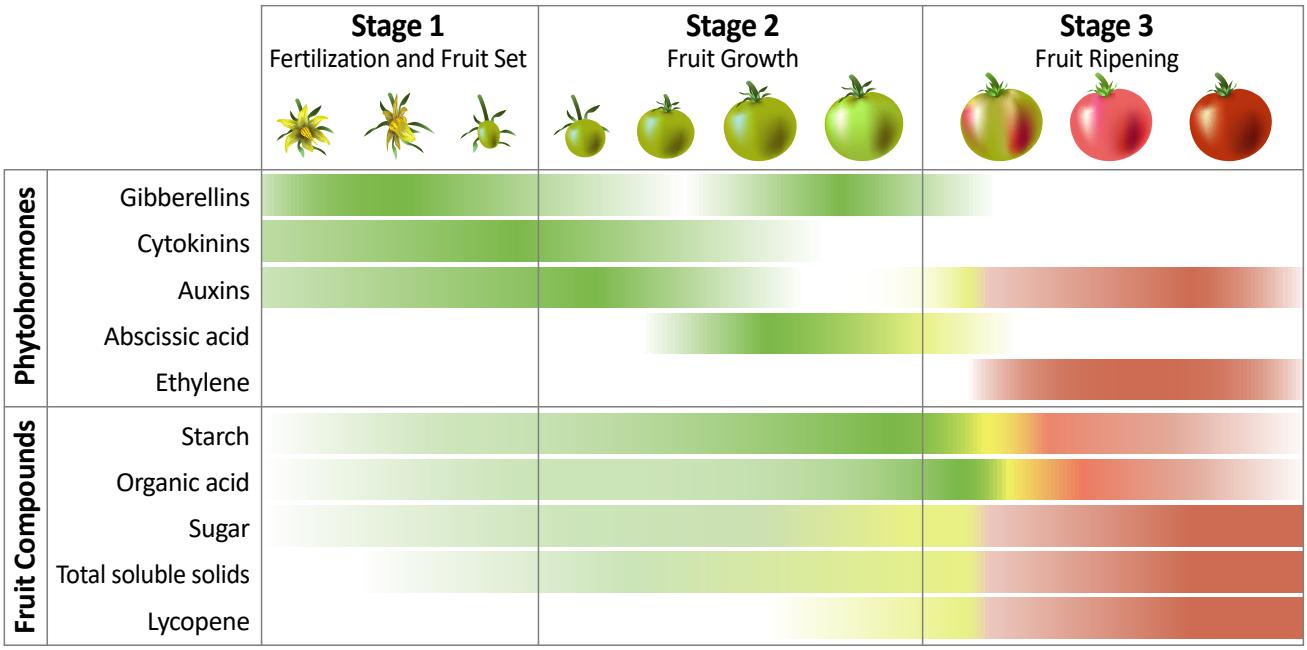

Figure 13. Hormone and fruit compound levels during tomato fruit development. Darker colours indicate higher levels and lighter colours indicate lower levels.

characterized by an increase in auxin, stage 2 is associated with an increase in abscisic acid, while in stage 3, ethylene accumulates during the final phases of fruit maturation and ripening. In fact, there is a dramatic 100-300 times increase in ethylene production and respiration rate as the tomato fruit matures. These ethylene-dependent changes allow tomatoes to mature and ripen after harvest, and that is why tomatoes are known as "climacteric fruit." Non-climacteric fruits, like strawberries, do not mature after harvest.

High Temperatures

High temperatures affect each stage of tomato fruit development. If greenhouse temperatures surpass 30˚C, pollination fails and fruit set is reduced in stage 1. Fruit development in stage 2 and fruit ripening in stage 3 also suffer under these conditions, leading to the development of physiological disorders, such as:

- fruit cracking
- green shoulder
- sunscald
- goldspot

Heat stress increases respiration rate and decreases photosynthesis in the whole plant. High temperatures and direct sunlight also reduce the level of lycopene (red colour) in the fruit by stimulating its conversion into ß-carotene (yellow colour). Lycopene formation is inhibited if temperatures are over 30˚C, whereas production of ß-carotene continues up to 40˚C. This leads to accumulation of carotene and reduction of lycopene in high heat.

Besides high temperatures, direct sunlight irradiation during the summertime also plays a role in the abnormal maturation of tomato fruit. Direct exposure to high sunlight levels by the fruit may increase the temperature of fruit tissue by 10˚C or more above ambient air temperature. A few hours at 30˚C will prevent normal pigment synthesis, reducing lycopene levels and therefore the red colour of the fruit. Fruit temperatures above 40˚C are lethal, and the exposed tissue will die, turn white, dry out and form a flat parchment-like covering over the affected area. This is typical of sunscald.

Fruit Cracking

Fruit cracking is a physiological disorder in tomatoes that can impact the marketability of fruit (Table 6). There are three types of fruit cracking:

1. **Radial Fruit Cracking (RFC)**
   Occurs when deep cracks jet from the calyx (stem) and down the fruit.
2. **Cuticular Cracking**
   Occurs when fine cracks appear in the surface of the fruit.
3. **Skin Cracking**
   Occurs just before harvesting in the pericarp surface (fleshy part of the tomato fruit).

Of these different types of cracking, RFC causes the most problems for producers because it spreads down the fruit during development. Serious cases of RFC may render fruit unmarketable. RFC occurs inside the cells of the pericarp rather than in the intercellular space (between cells). It is thought to be due to excess water and sugars flowing into the growing fruit, compromising cell structure and integrity and causing cells to rupture under the force. The risk of RFC increases if air temperatures in greenhouses exceed 25˚C during early fruit development. As air temperature rises it slows the rate of fruit cell division and growth resulting in fewer and smaller cells than under cooler temperatures. But since water and sugars are still being actively imported into these slowly

growing fruits the turgor pressure becomes more than the fruit cells can handle, making them more susceptible to RFC. Humidity is also correlated with RFC. The bigger the difference in humidity levels inside the greenhouse during the day and night, the higher the chances of RFC.

Sudden temperature changes or high day-night temperature differences favour the cracking of fruit. Changes from night to day temperatures need to be made before sunrise to avoid water vapour condensation on fruit. Low night temperature favours a negative pressure in fruit, whereas high day temperature increases both gas and hydrostatic pressure of fruit pulp on the skin, resulting in cracking in ripe fruit.

There is also a relationship between plant nutrition and fruit cracking. A study by Hao and Papdopoulos (2004b) showed that higher electrical conductivity (EC) levels in hydroponic nutrient solutions are associated with increased fruit firmness and elasticity and a reduction in cracking. More specifically, higher calcium (Ca) and magnesium (Mg) levels increase fruit elasticity and firmness, respectively, which reduce the chances of cracking. However, if magnesium levels are too high then the fruit becomes too firm which increases its susceptibility to cracking. Therefore, the calcium:magnesium ratio is an important factor to consider in fruit cracking.

A study by Peet and Willitis (1995) also showed that irrigation volume affects fruit cracking. When greenhouse tomatoes were irrigated with increasing volumes of nutrient solution, it was found that fruit number and weight sometimes increased and fruit quality consistently decreased because more irrigation caused more cracking. It is thought that overwatering increases the turgor pressure in developing fruits which leads to cracking. Producers should monitor the volume of leachate from their crops to ensure that they are not under- or over-watering.

The last factor discussed here that may influence fruit cracking is the number of fruit/cluster. A study by Demers et al (2007) showed that increasing the number of fruit/cluster of beefsteak tomatoes in the summertime improved fruit quality by reducing cracking. The authors suggested the number of fruit/cluster should be reduced during cooler seasons and increased during hotter seasons to balance the growth rate of the fruits with the environmental conditions. Less fruit/cluster in cooler temperatures allows for bigger fruit development, whereas more fruit/cluster in hotter temperatures reduces the size of the fruit but also improves fruit quality by reducing cracking. The authors of the study suggested the optimal number of beefsteak tomatoes/cluster should be 3 fruits/cluster in spring and fall, and that number should be increased as temperatures rise in the summer to 5 fruits/cluster.

Green Shoulder

Green shoulder (also called yellow shoulder or greenback) is characterized by green or yellow tissue under the peel near the stem of the fruit (shoulder) (Table 6). As the fruit ripens, these areas tend to become more green and yellow and never ripen properly, leading to green shoulder. The tissue is often hard, even when the rest of the tomato is ripe. Green shoulder is considered a ripening disorder. Like other ripening disorders it is more common in cultivars lacking the "uniform ripening" gene. Ripening disorders, however, are not strictly genetic because they are also associated with environmental factors, including high temperatures, light levels, relative humidity and crop nutrition.

High temperatures reduce photosynthesis and the amount of water and sugars that are transported to fruits and leaves. The lack of photosynthates (products of photosynthesis) moving through the phloem to fruits, flowers and seeds limits the amount of nutrients they receive. This results in a number

of deficiencies, including potassium (K) deficiency. The main physiological disorders associated with potassium deficiency are ripening disorders such as green shoulder. Potassium is thought to play an important role in green shoulder because there is a higher chance of tomato fruits developing the disorder if they are experiencing potassium deficiency—and tomato fruit exhibiting green shoulder have lower levels of potassium than normal fruit. An early symptom of potassium deficiency is leaf marginal necrosis, which is characterized by yellowing and browning of the tips on older leaves. Potassium is a highly mobile element in plants because it travels mainly in the phloem. If potassium deficiency occurs in the plant, it is transported from older parts of the plant (leaves) to younger organs that are growing (fruit). This is why marginal necrosis in older, lower leaves usually indicates potassium deficiency. Increasing the concentration of potassium and phosphorus (P) in the nutrient solution will help promote uptake of potassium and reduce the occurrence of yellow shoulder. You can find more information about nutrient deficiency symptoms in Publication 836B, Chapter 12: *Nutrients and Analytic Testing*.

Green shoulder also develops when the fruit is exposed to direct sunlight during development. Remember that direct sunlight degrades the red lycopene pigment. More specifically, green shoulder is affected by infrared and shortwave radiation. The intensity of red light also has a positive effect on synthesis of the green/yellow carotenoid pigment that contributes to yellowing of the fruit tissue.

A multi-pronged strategy recommended to reduce the occurrence of green shoulder under high temperatures includes increased shading of fruit and promotion of potassium uptake. For example, phosphorus supplementation significantly improves growth of upper leaves that provide shade for developing fruits in the lower part of the plant, and it promotes uptake of potassium as well as other nutrients (nitrogen (N), calcium (Ca) and magnesium (Mg).

Sunscald

Besides developing green shoulder, immature fruit exposed to direct sunlight ripen unevenly so yellow patches appear on the side of the tomato fruit. This disorder is called sunscald, sunburn or sunscorch. Similar to green shoulder, the texture of affected areas is leathery and firmer than the surrounding tissues. These yellow areas sometimes have a mottled appearance and a depressed surface (Table 6). Unlike green shoulder, which is thought to have a genetic component, sunscald is associated more with environmental conditions. It is caused when the fruit pericarp (fleshy part) reaches temperatures exceeding 40˚C. How can fruits reach such high temperatures? Fruits that are directly exposed to strong sunlight with no shade can be more than 10˚C higher than the surrounding air. The degree of injury to the fruit depends on light intensity, light spectral quality, temperature and duration. Promoting upper leaf growth that helps to shade the fruit during growth and applying whitewash on glazing materials to reduce exposure to direct sunlight are effective ways to reduce sunscald.

Goldspot

Yellow specks and flecks are often observed around the calyx and shoulders of mature fruit during summer production. This is known as goldspot or goldspeck (Table 6). Before tomatoes are mature these specks appear white in colour. They are less abundant in green fruit.

Goldspot has been identified as cells containing calcium oxalate crystals. These tiny yellowish spots are usually less than 0.1 µm across and often observed around the calyx and shoulders. Their presence affects the external appearance of the fruit

and reduces their shelf-life. In contrast to blossom end rot (BER) that is associated with calcium (Ca) deficiency, goldspot is a result of excess levels of calcium in the fruit. When the greenhouse environment does not promote transpiration through the leaves, like when there's high humidity levels, more calcium is transported to the fruit than the leaves. This is because calcium is an immobile element, meaning that it is mainly transported in the xylem with water, unlike potassium (K) that is mainly transported in the phloem with sugars. High calcium:potassium ratios and increased phosphorus (P) levels also promote uptake of calcium and may result in higher calcium concentrations in the fruit and higher incidence of goldspot. Goldspot can be managed by increasing nitrate (NO_3) or magnesium (Mg) or reducing chloride (Cl) or ammonium (NH_4) in the nutrient solution to reduce uptake of calcium (Ca). This disorder can also be reduced by avoiding susceptible cultivars. For example, cultivars resistant to BER tend to be more susceptible to goldspot because they are more efficient at taking up calcium.

The temperature of the rooting system also has an influence on the rate of absorption of nutrients. For example, increasing the temperature of the rooting system from 14˚C to 26˚C increases rate of absorption of calcium and potassium by 45% and 64%, respectively. Therefore, it is important to prevent the temperature of fertigation rising too high. There's a fine balance between providing the crop with enough calcium to avoid BER, and not too much calcium that it causes goldspot.

Conclusions and Recommendations

Many of the physiological disorders discussed here can be avoided by shading the greenhouse and/or fruit in the summertime. This can be done by coating the greenhouse exterior with glazing products to reduce the amount of light entering the greenhouse and/or using shade curtains. Promoting upper leaf development to shade lower developing fruit can also help reduce fruit exposure to direct sunlight. Fog cooling is another technique that can be used to keep greenhouse temperatures in check. Furthermore, monitoring for nutrient deficiencies, adjusting the nutrient composition of the fertigation accordingly and employing irrigation techniques that are appropriate for the changing growing conditions will help to avoid these physiological disorders.

References

Aslani et al. 2020. *The relationship between tomato fruit growth, incidence of blossom-end rot and phytohormone content as affected by sink/source ratio*. Annals of Applied Biology. 2:1.

Barickman et al. 2019. *Applications of Abscisic Acid and Increasing Concentrations of Calcium Affect the Partitioning of Mineral Nutrients between Tomato Leaf and Fruit Tissue*. Horticulturae. 5:49.

Demers et al. 2007. *Yield and Russeting of Greenhouse Tomato as Influenced by Leaf-to-fruit Ratio and Relative Humidity*. HortScience. 42:503.

Dorais et al. 2000. *Greenhouse Tomato Fruit Quality*. Horticultural Reviews. 26:239.

Gaion et al. 2019. *Amplification of gibberellins response in tomato modulates calcium metabolism and blossom end rot occurrence*. Scientia Horticulturae. 246:498.

Hagassou et al. 2019. *Blossom end-rot in tomato (Solanum lycopersicum L.): A multi-disciplinary overview of inducing factors and control strategies*. Scientia Horticulturae. 249:49.

Hao and Papadopoulos. 2004a. *Effects of Calcium and Magnesium on Plant Growth, Biomass Partitioning, and Fruit Yield of Winter Greenhouse Tomato*. HortScience. 39:512.

Hao and Papadopoulos. 2004b. *Effects of Electrical Conductivity and Mineral Nutrition on Fruit Radial*. Acta Hort. 633:365.

Hernandez-Perez et al. 2019. *Tomato Fruit Yield, Quality, and Nutrient Status in Response to Potassium: Calcium Balance and Electrical Conductivity in the Nutrient Solution*. Journal of Soil Science and Plant Nutrition. 20:484.

Hou et al. 2020. *Responses of water accumulation and solute metabolism in tomato fruit to water scarcity and implications for main fruit quality variables*. Journal of Experimental Botany. 71:1249.

Indeche et al. 2020. *Effect of Defoliation on Blossom-end Rot Incidence and Calcium Transport into Fruit of Tomato Cultivars Under Moderate Water Stress*. The Horticulture Journal. 89:22.

Marten et al. 2020. *Short- and long-term phenotypic changes of hydroponically grown tomatoes as a result of seedling production substrates.* European Journal of Horticulture Science. 85:92.

Mayorga-Gomez et al. 2020. *Temporal Relationship between Calcium and Fruit Growth and Development in Bell Pepper (Capsicum annuum L.)*. HortScience. 55:906.

Millones-Chanamé et al. 2019. *Inheritance of blossom end rot resistance induced by drought stress and of associated stomatal densities in tomatoes*. Euphytica. 215:120.

Mulholland et al. 2003. *Effects of high temperature on tomato summer fruit quality*. Journal of Horticulautral Sciences and Biotechnology. 78:365.

Peet. 2009. *Physiological Disorders in Tomato Fruit Development*. Acta Hor. 821:16.

Peet and Willitis. 1995. *Role of Excess Water in Tomato Fruit Cracking*. HortScience. 30:65.

Quinet et al. 2019. *Tomato Fruit Development and Metabolism*. Frontiers in Plant Science. 10:1554.

Riboldi et al. 2019. *24-Epibrassinolide Mechanisms Regulating Blossom-End Rot Development in Tomato Fruit*. Journal of Plant Growth Regulation. 38:812.

Saltveit. 2005. *Tomatoes: Chapter 5, Fruit Ripening and Fruit Quality*. CABI Publishing.

Shao et al. 2018. *Relationship between rhizosphere soil properties and blossom-end rot of tomatoes in coastal saline-alkali land*. Applied Soil Ecology. 127:96.

Suzuki. 2019. *Physiological Disorders and Their Management in Greenhouse Tomato Cultivation at High Temperatures*. Adaptation to Climate Change in Agriculture. Springer Publishing, pp 81.

Zhang et al. 2018. *Fruit yellow-shoulder disorder as related to mineral element uptake of tomatoes grown in high temperature*. Scientia Horticulturae. 242:25.

Photo Credits (Table 6)

Blocky Fruit, Source: Copilot for Microsoft 365
Retrieved October 24, 2025
Prompt: Generate an image of a blocky tomato.
Response: Here's a generated image of a blocky tomato, showing a square-like shape with defined edges and slightly flattened sides — typical of certain greenhouse varieties bred for uniformity and firmness.

Catface, Source: Copilot for Microsoft 365
Retrieved October 24, 2025
Prompt: Generate an image of catface tomato.
Response: Here's a generated image of a tomato showing catface disorder—characterized by severe scarring and malformation near the blossom end, often caused by cool temperatures during flower development or incomplete pollination.

Goldspot, Source: Shuttestock, 55417714 Overhead View Cherry Tomatoes.

Puffiness or Hollowness
Source: Copilot for Microsoft 365
Retrieved October 24, 2025
Prompt: Generate an image of a tomato with puffiness disorder or hollowness disorder.
Response: Here's a generated image of a tomato showing puffiness/hollowness disorder —characterized by irregular lobes and a hollow cavity inside the fruit, often linked to poor pollination or nutrient imbalance.
Prompt: make the image without a hole in the fruit.
Response: Here's the updated image of a tomato with puffiness/hollowness disorder, now without an external hole—showing the characteristic lobed and irregular shape while keeping the surface intact.

Goldspot, Source: Shuttestock, 1789398950 Sunburn - Sunscald on tomatoes fruit.

Appendix A. Ministry Resources

Agricultural Information Contact Centre
Province-wide, technical and business information to commercial farms and agri-businesses.
Tel: 1-877-424-1300
E-mail: ag.info.omafa@ontario.ca

ONGreenhouseVegetables

For the latest information on:

- Commercial controlled environment agriculture including greenhouse fruits, vegetables and vertical farming
- Timely updates and technical information on production and integrated pest management
- GrowON educational series workshops/webinars
- Greenhouse Vegetable Course

Visit the Blog at
ONGreenhouseVegetables.ca

Ontario Crop Protection Hub

Use this tool on any device to find:

- Proper rates and application protocols for legally registered insecticides, fungicides and herbicides
- Up-to-date information on product efficacy against pests
- Strategies to support environmental stewardship
- Information to help growers manage pesticide resistance

Visit the Ontario Crop Protection Hub at
Ontario.ca/cropprotection

CropIPM

IPM info at your fingertips. The new CropIPM tool includes:

- Up-to-date IPM information for key Ontario pests
- A new 'Identify' feature to help you identify pests and disorders
- An expanded offering of crop specific information
- Scouting calendars
- Comparisons of often-confused-with pests
- Details on soil diagnostics and herbicide injury

Visit the CropIPM tool at
Ontario.ca/cropIPM

Appendix B. Other Resources

Agriculture & Agri-Food Canada (AAFC)
Agriculture and Agri-Food Canada supports the Canadian agriculture and agri-food sector through initiatives that promote innovation and competitiveness.
https://agriculture.canada.ca/en

AAFC Research Centres
www.agriculture.canada.ca/en/agricultural-science-and-innovation/agriculture-and-agri-food-research-centres-and-collections

Canadian Food Inspection Agency — Plant Protection
Services and information on plant pests and invasive species, import, export, trade, fertilizers, soil and soil-related matter, grains and field crops, seeds, cannabis, forestry, horticulture. https://inspection.canada.ca/en/plant-health

Canadian Greenhouse Conference
The Canadian Greenhouse Conference is a not-for-profit corporation and Canada's foremost event and connection point for commercial growers of crops produced in a controlled environment.
https://www.canadiangreenhouseconference.com/

Greenhouse Canada
National business magazine published exclusively for commercial greenhouse growers in Canada.
https://www.greenhousecanada.com/

University of Guelph — Plant Agriculture
Canada's largest and most diverse applied plant biology department. A research intensive department within the Ontario Agricultural College dedicated to teaching, research and service related to horticultural crops, turfgrass, landscape species and field crops. www.plant.uoguelph.ca

Lab Services Division
www.uoguelph.ca/labserv/

Appendix C. Metric System and Abbreviations

Metric units

Linear measures (length)		
10 millimetres (mm)	=	1 centimetre (cm)
100 centimetres (cm)	=	1 metre (m)
1,000 metres	=	1 kilometre (km)
Square measures (area)		
100 m × 100 m = 10,000 m^2	=	1 hectare (ha)
100 ha	=	1 square kilometre (km^2)
Cubic measures (volume)		
Dry measure		
1,000 cubic millimetres (mm^3)	=	1 cubic centimetre (cm^3)
1,000,000 cm^3	=	1 cubic metre (m^3)
Liquid measure		
1,000 millilitres (mL)	=	1 litre (L)
100 L	=	1 hectolitre (hL)
Weight-volume equivalents (for water)		
(1.00 kg) 1,000 grams	=	1 litre (1.00 L)
(0.50 kg) 500 g	=	500 mL (0.50 L)
(0.10 kg) 100 g	=	100 mL (0.10 L)
(0.01 kg) 10 g	=	10 mL (0.01 L)
(0.001 kg) 1 g	=	1 mL (0.001 L)
Weight measures		
1,000 milligrams (mg)	=	1 gram (g)
1,000 g	=	1 kilogram (kg)
1,000 kg	=	1 tonne (t)
1 mg/kg	=	1 part per million (ppm)
Dry–liquid equivalents		
1 cm^3	=	1 mL
1 m^3	=	1,000 L
Metric conversions		
5 mL	=	1 tsp
15 mL	=	1 tbsp
28.5 mL	=	1 imp. fl. oz.

Handy metric conversion factor (approximate)

litres per hectare × 0.4	=	litres per acre
kilograms per hectare × 0.4	=	kilograms per acre

Application rate conversions

Metric to imperial or U.S. (approximate)		
litres per hectare × 0.09	=	Imp. gallons per acre
litres per hectare × 0.11	=	U.S. gallons per acre
litres per hectare × 0.36	=	Imp. quarts per acre
litres per hectare × 0.43	=	U.S. quarts per acre
litres per hectare × 0.71	=	Imp. pints per acre
litres per hectare × 0.86	=	U.S. pints per acre
millilitres per hectare × 0.014	=	U.S. fluid ounces per acre
grams per hectare × 0.014	=	ounces per acre
kilograms per hectare × 0.89	=	pounds per acre
tonnes per hectare × 0.45	=	tons per acre
Imperial or U.S. to metric (approximate)		
Imp. gallons per acre × 11.23	=	litres per hectare (L/ha)
U.S. gallons per acre × 9.35	=	litres per hectare (L/ha)
Imp. quarts per acre × 2.8	=	litres per hectare (L/ha)
U.S. quarts per acre × 2.34	=	litres per hectare (L/ha)
Imp. pints per acre × 1.4	=	litres per hectare (L/ha)
U.S. pints per acre × 1.17	=	litres per hectare (L/ha)
Imp. fluid ounces per acre × 70	=	millilitres per hectare (mL/ha)
U.S. fluid ounces per acre × 73	=	millilitres per hectare (mL/ha)
tons per acre × 2.24	=	tonnes per hectare (t/ha)
pounds per acre × 1.12	=	kilograms per hectare (kg/ha)
pounds per acre × 0.45	=	kilograms per acre (kg/acre)
ounces per acre × 70	=	grams per hectare (g/ha)

Dry weight conversions (approximate)

Metric		**Imperial**
grams or kilograms/hectare		**ounces or pounds/acre**
100 g/ha	=	1½ oz/acre
200 g/ha	=	3 oz/acre
300 g/ha	=	4¼ oz/acre
500 g/ha	=	7 oz/acre
700 g/ha	=	10 oz/acre
1.10 kg/ha	=	1 lb/acre
1.50 kg/ha	=	1¼ lb/acre
2.00 kg/ha	=	1¾ lb/acre
2.50 kg/ha	=	2¼ lb/acre
3.25 kg/ha	=	3 lb/acre
4.00 kg/ha	=	3½ lb/acre
5.00 kg/ha	=	4½ lb/acre
6.00 kg/ha	=	5¼ lb/acre
7.50 kg/ha	=	6¾ lb/acre
9.00 kg/ha	=	8 lb/acre
11.00 kg/ha	=	10 lb/acre
13.00 kg/ha	=	11½ lb/acre
15.00 kg/ha	=	13½ lb/acre

Conversion tables – metric to imperial (approximate)

Length		
1 millimetre (mm)	=	0.04 inches
1 centimetre (cm)	=	0.40 inches
1 metre (m)	=	39.40 inches
1 metre (m)	=	3.28 feet
1 metre (m)	=	1.09 yards
1 kilometre (km)	=	0.62 miles
Area		
1 square centimetre (cm^2)	=	0.16 square inches
1 square metre (m^2)	=	10.77 square feet
1 square metre (m^2)	=	1.20 square yards
1 square kilometre (km^2)	=	0.39 square miles
1 hectare (ha)	=	107,636 square feet
1 hectare (ha)	=	2.5 acres

Volume (dry)		
1 cubic centimetre (cm^3)	=	0.061 cubic inches
1 cubic metre (m^3)	=	1.31 cubic yards
1 cubic metre (m^3)	=	35.31 cubic feet
1,000 cubic metres (m^3)	=	0.81 acre-feet
1 hectolitre (hL)	=	2.8 bushels
Volume (liquid)		
1 millilitre (mL)	=	0.035 fluid ounces (Imp.)
1 litre (L)	=	1.76 pints (Imp.)
1 litre (L)	=	0.88 quarts (Imp.)
1 litre (L)	=	0.22 gallons (Imp.)
1 litre (L)	=	0.26 gallons (U.S.)
Weight		
1 gram (g)	=	0.035 ounces
1 kilogram (kg)	=	2.21 pounds
1 tonne (t)	=	1.10 short tons
1 tonne (t)	=	2,205 pounds
Pressure		
1 kilopascal (kPa)	=	0.15 pounds/$in.^2$
Speed		
1 metre per second	=	3.28 feet per second
1 metre per second	=	2.24 miles per hour
1 kilometre per hour	=	0.62 miles per hour
Temperature		
˚F	=	(˚C × 1.8) + 32

Conversion tables – imperial to metric (approximate)

Length		
1 inch	=	2.54 cm
1 foot	=	0.30 m
1 yard	=	0.91 m
1 mile	=	1.61 km
Area		
1 square foot	=	0.09 m^2
1 square yard	=	0.84 m^2
1 acre	=	0.40 ha
Volume (dry)		
1 cubic yard	=	0.76 m^3
1 bushel	=	36.37 L
Volume (liquid)		
1 fluid ounce (imp.)	=	28.41 mL
1 pint (imp.)	=	0.57 L
1 gallon (imp.)	=	4.55 L
1 gallon (U.S.)	=	3.79 L
Weight		
1 ounce	=	28.35 g
1 pound	=	453.6 g
1 ton	=	0.91 tonne
Pressure		
1 pound per square inch	=	6.90 kPa
Temperature		
˚C	=	(˚F – 32) × .5556

Abbreviations

%	=	per cent
cm	=	centimetre
cm^2	=	square centimetre
EC	=	electrical conductivity
e.g.	=	for example
g	=	gram
hr	=	hour
ha	=	hectare
HP	=	horsepower
J	=	joule
kg	=	kilogram
km/h	=	kilometres per hour
kPa	=	kilopascal
L	=	litre
m	=	metre
m^2	=	square metre
mJ	=	millijoule
mL	=	millilitre
mol	=	mole
mm	=	millimetre
mS	=	milliSiemes
m/s	=	metres per second
nm	=	nanometres
ppm	=	parts per million
s or sec	=	second
t	=	tonne
µ	=	micro
µm	=	micrometres
µmol	=	micromole
W	=	Watts

Nutrient Abbreviations

B	=	Boron
Ca	=	Calcium
Cl	=	Chloride
Cu	=	Copper
Fe	=	Iron
HCO_3	=	Bicarbonate
K	=	Potassium
Mg	=	Magnesium
Mn	=	Manganese
Mo	=	Molybdenum
N	=	Nitrogen
NH_4	=	Ammonium
P	=	Phosphorus
S	=	Sulfur
Zn	=	Zinc

Notes

ontario.ca/crops