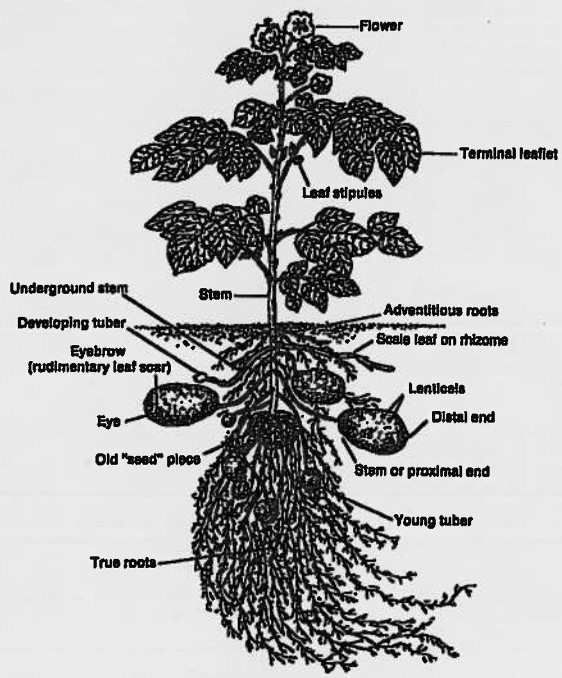
1 Botany of the Potato Plant

1.1 The Potato Plant and Tubers

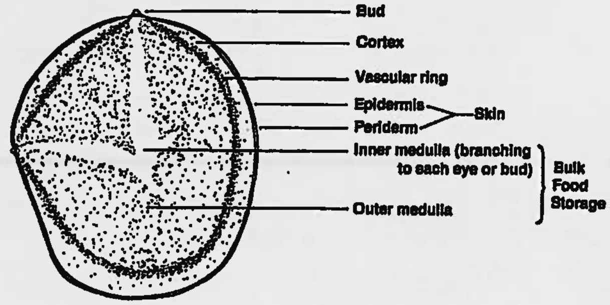
The potato tuber is an enlarged portion of an underground stem or stolon (Figure 1.1-1). Tuber eyes are the buds from which next season's growth will emerge. Eyes are concentrated near the apical end of the tuber, with fewer near the stolon or basal end. Eye number and distribution are characteristic of the variety.

Figure 1.1-1 Diagram of a potato plant. For simplicity, one main stem is shown. Productive plants may have two or more main stems. (Courtesy of Alberta, Food and Rural Development)



The tuber skin is composed of two layers of cells: an outer layer of single cells called the epidermis, underlain by several layers of corky cells called the periderm (Figure 1.1-2). The cells in the periderm layer may contain a pigment that produces coloured potatoes. Below the periderm is the cortex, followed by the vascular ring, which contains the cells that transport food products to the tuber from the above ground stems. Internal to the vascular ring is the medulla. The medulla represents the primary storage area for the potato tuber. Excess food produced by the potato plant is transported to the medulla via the vascular tissue. Cells in the medulla increase in number and size as they are supplied with food, causing the tuber to increase in size.

Figure 1.1-2 Cross-section of a potato tuber (Courtesy of Alberta Agriculture, Food and Rural Development)



1.2 Potato Plant Growth

Growth and quality of potatoes are influenced by environmental factors such as temperature, moisture, light, soil type and nutrients. Many factors that influence potato growth are largely uncontrollable: length of growing season, air and soil temperatures, light intensity and duration, humidity and wind. Other factors that influence growth of the crop can be controlled by the grower: variety of potato, size of mother seed tubers, seed-piece cutting, seed-piece types, cut-seed size, planter operation, plant stand, stem population, moisture, nutrition, pest management, planting date and harvest date. Only when all factors are at optimum levels can the most profitable yields of quality potatoes be attained.

Temperature and length of growing season

The potato is a cool-season crop that grows well in certain areas of the Prairie Provinces. The rate of development of sprouts from seed pieces depends on soil temperature. Very little sprout elongation occurs at 43°F (6°C), elongation is slow at 48°F (9°C) and is maximized at about 64°F (18°C). The optimum soil temperature for initiating tubers is 61-66°F (16-19°C). Tuber development declines as soil temperatures rise above 68°F (20°C) and tuber growth practically stops at soil temperatures above 86°F (30°C). The number of tubers set per plant is greater at lower temperatures than at higher temperatures, whereas higher temperatures favour development of large tubers.

Yields are highest when average daytime temperatures are about 69°F (21°C). Cool night temperatures are important because they affect the accumulation of carbohydrates and dry matter in the tubers. At lower night temperatures, respiration is slowed, which enhances storage of starch in the tubers.

From the temperature information in the above paragraphs Physiological Days (P-Days) can be calculated. P-Days are a measure of the heat useful for the growth and development of potatoes. In the potato production areas of the Prairies, the highest average accumulation of P-Days, 850-950, occurs south of Lake Manitoba to the U.S. border and the lowest accumulation, 750-900, occurs in the seed production areas south of Edmonton and in Central Saskatchewan (Plate 1).

The varieties currently grown on the Prairies require anywhere from 800-1000 P-Days to reach full maturity. An early-maturing variety such as Norland requires 800 P-Days, and later maturing varieties such as Russet Burbank require 1000 P-Days. Growing a potato variety in an area with insufficient P-Days will reduce yield and affect tuber quality factors such as accumulation of solids and fry colour (See 1.5 *Tuber Quality*). The average accumulation of P-Days is insufficient in many parts of the Prairies to produce late season varieties where the crop must be fully mature before harvest. These areas may be suitable for seed or table production, where the crop is killed or harvested before full maturity.

Moisture

Potatoes require a continuous supply of soil water along with adequate soil aeration. Yields are greatest when soil moisture is maintained above 65% of the available soil water (ASW) capacity

Tuber set is particularly sensitive to moisture stress. There are generally fewer tubers set when available soil moisture is maintained below 65% of the available soil water (ASW) capacity. The amount of water needed by potatoes varies with the soil type, temperature, humidity, air movement, plant and stem populations, variety and cultural practices. In Alberta and Saskatchewan, too little moisture and fluctuating moisture levels are more common than excessive moisture. In Manitoba, the situation is reversed. Too much moisture generally causes more problems than too little moisture. Low or fluctuating moisture levels can contribute to common scab, early dying, hollow heart, knobby tubers, low dry matter, low tuber set, and low yield. Excessive soil moisture resulting in poor aeration and water logging of the soil reduces yields and in extreme cases causes tuber rot. An excess of moisture may also lead to enlarged lenticels, which are openings of the epidermis. This detracts from their appearance and allows entry of disease organisms, causing tuber rot in storage.

1.3 Growth Stages

The development of potatoes can be broken down into five distinct growth stages (Figure 1.3-1).

Growth Stage I: Sprout Development

This stage begins with sprouts developing from the eyes and ends at emergence from the soil. The seed piece is the sole energy source for growth during this stage.

Growth Stage II: Vegetative Growth

This stage, in which all vegetative parts of the plants (leaves, branches, roots and stolons) are formed, begins at emergence and lasts until tubers start to develop. Growth stages I and II last from 30 to 70 days depending on planting date, soil temperature and other environmental factors, the physiological age of the tubers, and the characteristics of particular cultivars.

Growth Stage III: Tuber Set/Initiation

Tubers are forming at salon tips, but are not yet enlarging. This stage will last approximately 2 weeks.

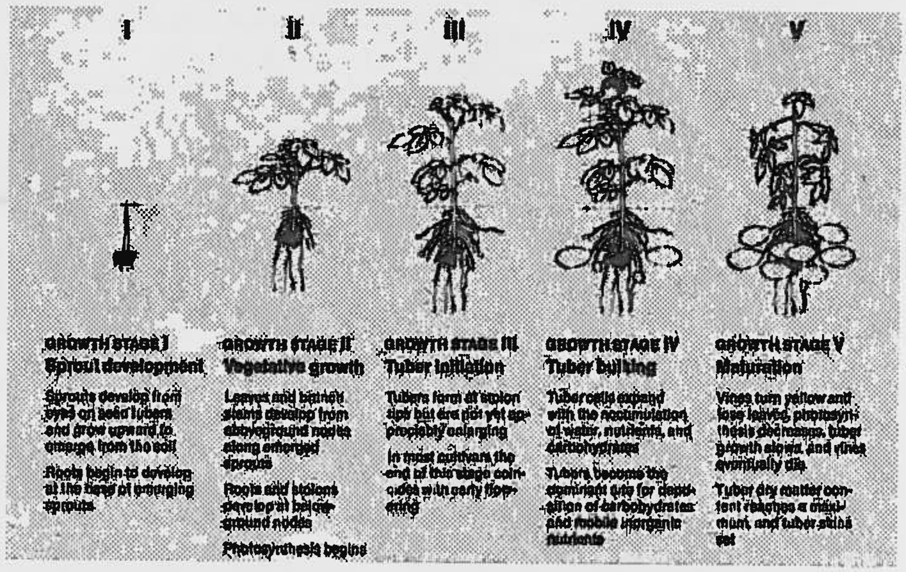
Growth Stage IV: Tuber Bulking

Tuber cells expand with the accumulation of water, nutrients and carbohydrates. Tuber bulking is the growth stage of longest duration. Depending on date of planting and cultivar, bulking can last up to three months.

Growth Stage V: Maturation

Vines turn yellow and lose leaves, photosynthesis gradually decreases, tuber growth rate slows and the vines die. This stage may not occur when growing a long season variety like Russet Burbank in a production area with a short growing season.

Figure 1.3-1 Growth stages of the potato. (Courtesy of the American Phytopathological Society)



1.4 Tuber Initiation and Growth

Growth Stage III (Figure 1.3-1) tuber initiation or tuberization starts when the ends of stolons begin to swell. This occurs between early and late June depending on location, planting date, climate, soil type, and variety. Tubers form when the plant produces more carbohydrates than are required for vine growth. Varying weather and moisture conditions cause uneven tuber set and growth.

The number of tubers formed per plant is called the tuber set. The plant may initially produce 20 to 30 small tubers, but only 5 to 15 tubers typically reach maturity. The growing plant absorbs some of the tubers in the original set. The number of tubers that achieve maturity is related to available moisture and nutrition. Optimum moisture and nutrient levels early in the growing season are critical to the maintenance and development of tubers. Maintaining available soil moisture above 65% of the available soil water (ASW) capacity has been shown to produce high tuber set when compared to lower moisture levels.

Uneven growth of the potato plant, and therefore uneven growth of tubers, can result in abnormalities in tuber shape. Fluctuating temperatures, moisture, and nitrogen, especially in the formative stage, can cause malformed tubers. Uneven growth caused by variable climactic conditions is worsened by poor plant stand and variability between plants caused by variable seed-piece types, sizes and spacings.

1.5 Tuber Quality (M. Scanlon)

Nutritional Quality

Potatoes are a nonfattening, nutritious and wholesome food that supplies many important nutrients to the diet. Potatoes contain approximately 78% water, 22% dry matter (specific gravity) and less than 1% fat. About 82% of dry matter is carbohydrate, mainly starch, with some dietary fibre and small amounts of various simple sugars.

Potatoes are a nonfattening, nutritious and wholesome food that supplies many important nutrients to the diet.

Although potatoes contain only relatively little protein (0.6-1.2% of the fresh weight), their nutritional quality is better than cereals or soybeans. Potatoes contain at least 12 essential vitamins and minerals, are a source of vitamin C, thiamine, iron and folic acid.

Fresh-Market

Quality influences consumer preference and product saleability. Good quality potatoes are clean, uniform in shape and size, have an unmarked skin and firm flesh, are free of internal defects, and have shallow eyes. Consumers do not like the waste of trimming potatoes with deep eyes and surface defects. Other tuber defects that may adversely influence quality are greening, secondary growth, growth cracks, scab, storage rots, internal black spot, skinning, *Rhizoctonia* sp. sclerotia, bruising and skinning or other mechanical damage.

In addition to physical quality and appearance, fresh market potatoes must also have good cooking and eating quality. The main cooking quality factors for home-prepared potatoes are texture, colour, flavour and odour. The texture of a cooked potato is directly related to dry matter content. Potatoes are described as mealy and dry if they have a high dry matter content, or moist to wet with a low dry matter. Potatoes such as Russet Burbank, which have a high dry matter content, have a dry, mealy texture when baked, but when boiled they may slough or break up. Potatoes, such as Norland, with a lower specific gravity are inclined to be undesirably wet when baked, but hold together well when boiled.

White-fleshed potatoes are expected to have a creamy white colour when boiled or baked. Yellow-fleshed varieties should retain their characteristic yellow colour during cooking. White or yellow-fleshed potatoes should exhibit minimal after-cooking darkening. This darkening, which is often more prevalent at the stem end of the tuber, is caused by an accumulation of a dark pigment created by the reaction between chlorogenic acid and iron, both naturally occurring compounds in potatoes. Varieties such as Norland, which naturally contain higher amounts of chlorogenic acid, darken more than varieties containing less chlorogenic acid. In the home, after-cooking darkening may be controlled with lemon juice or vinegar (which contain acid). In the commercial potato processing industry sodium acid pyrophosphate is used to reduce darkening after cooking.

Cooked potatoes are expected to have "normal" potato flavour and aroma, without off-flavours or odours. Glycoalkaloids, such as solanine and chaconine, which are present at low levels (2-15 mg/100 g fresh tuber weight) in all potatoes, represent important flavour components. Collectively, this class of compounds is referred to as total glycoalkaloids (TGA). If TGA levels are between 10 and 20 mg/100 g fresh weight the potatoes are bitter when eaten and are potentially toxic if levels are greater than 20 mg/100 g. Twenty (20)mg TGA/100g fresh weight is the maximum allowed by Health Canada.

Surface greening of the tubers often signals the development of bitterness due to TGA accumulation, although the development of the bitter alkaloid compounds and green colour are independent. When potatoes are exposed to light, the green pigment chlorophyll forms, and independent chemical reactions in the outer layer of the potato tuber are triggered, increasing TGA levels. Moderately green tubers should not be consumed without first taste testing the peel of several raw tubers. Bitterness or a burning sensation indicates that TGA levels are too high and the potatoes should be discarded. Elevated TGA levels in potatoes may result not only from exposure to light but also from harvesting immature potatoes, bruising, skinning, improper storage temperature control, wet conditions prior to harvest, chilling or freezing. Potatoes harvested cold should be slowly warmed to 40-50°F (10-15°C) for 14 days after harvest before the temperature is reduced for long-term storage. Unlike other problems associated with potato quality such as after-cooking darkening, TGA accumulation cannot be counteracted with chemicals or special processing techniques. Not all glycoalkaloids leach from potatoes into blanching or cooking water, and they are not destroyed at the high temperatures associated with boiling, baking or deep-frying.

French Fry Quality

Four primary factors determine French fry quality: dry matter, levels of reducing sugars, defects and flavour. One of the most important qualities of French fry potatoes is high dry matter, which is measured as specific gravity or percent solids. As the specific gravity increases, the water content of the potato decreases. French fry processing removes water from the potato, hence the higher the water content of the potato, the more water or weight lost during processing resulting in a lower yield of fries. Potatoes with a high specific gravity produce a greater yield of fries than potatoes with low specific gravity. Specific gravity also has a direct bearing on the amount of oil absorbed by the potato slices during the deep frying process. Fries made from tubers with low specific gravity absorb more oil than fries from tubers with high specific gravity. Although some oil absorption during deepfrying is desirable for flavour development, too much results in limp, greasy fries. Low specific gravities increase production costs because more oil is used in the frying process.

One of the most important qualities of French fry potatoes is high dry matter.

French fries should have a uniform light cream to golden colour. French fry colour is largely determined by the reducing sugar content of the potato tuber: potatoes with high reducing sugar levels make dark fries. When potatoes are fried, the reducing sugars react with amino acids in the tuber to form dark products in a nonenzymatic browning reaction. The concentration reducing sugars in the tubers depends on variety, growing conditions, maturity, and storage conditions. The processor can make some adjustments to fry colour during processing, primarily by manipulating blanching conditions. Plate #2 shows the range of fry colours that occur. Processors prefer the lightest fry colour shown in Plate 2. Defects such as sunburn, net necrosis, sugar ends, bruises, carbon spots and light and dark brown areas, negatively influence the appearance of the finished French fry and reduce its value on the market.

High quality French fries have a good potato flavour, are free from rancidity, bitterness, or offodours. Their external surfaces should be moderately crisp showing no separation from the inner portion. The inside is tender, mealy and free from sogginess. The contrast in texture between inner and outer portions contributes to the pleasurable textural sensation when the fries are chewed. Some fries have a coating applied (e.g., starch paste based coatings) to enhance this textural contrast.

Potato Chip Quality

Good quality potato chips have a light colour with little vascular discolouration. As with French fries, the colour of potato chips depends on the reducing sugar content of the potatoes. However, potato chip processors have slightly less control over reducing sugar levels because blanching is not an option in the chipping process. High specific gravity is particularly important in the production of potato chips because of greater surface area to volume ratio in chips compared to fries. Chip crispness and lack of oiliness increases with increasing specific gravity.

Potato chips must have a pleasing and desirable flavour, thus potatoes used in chipping must not be bitter or have other off-flavours. The flavour of potato chips is more complex than that of boiled, baked or mashed potatoes, since the cooking temperatures are higher, and the absorbed oil contributes to the overall flavour profile of the product.

7.0 Colour Plates

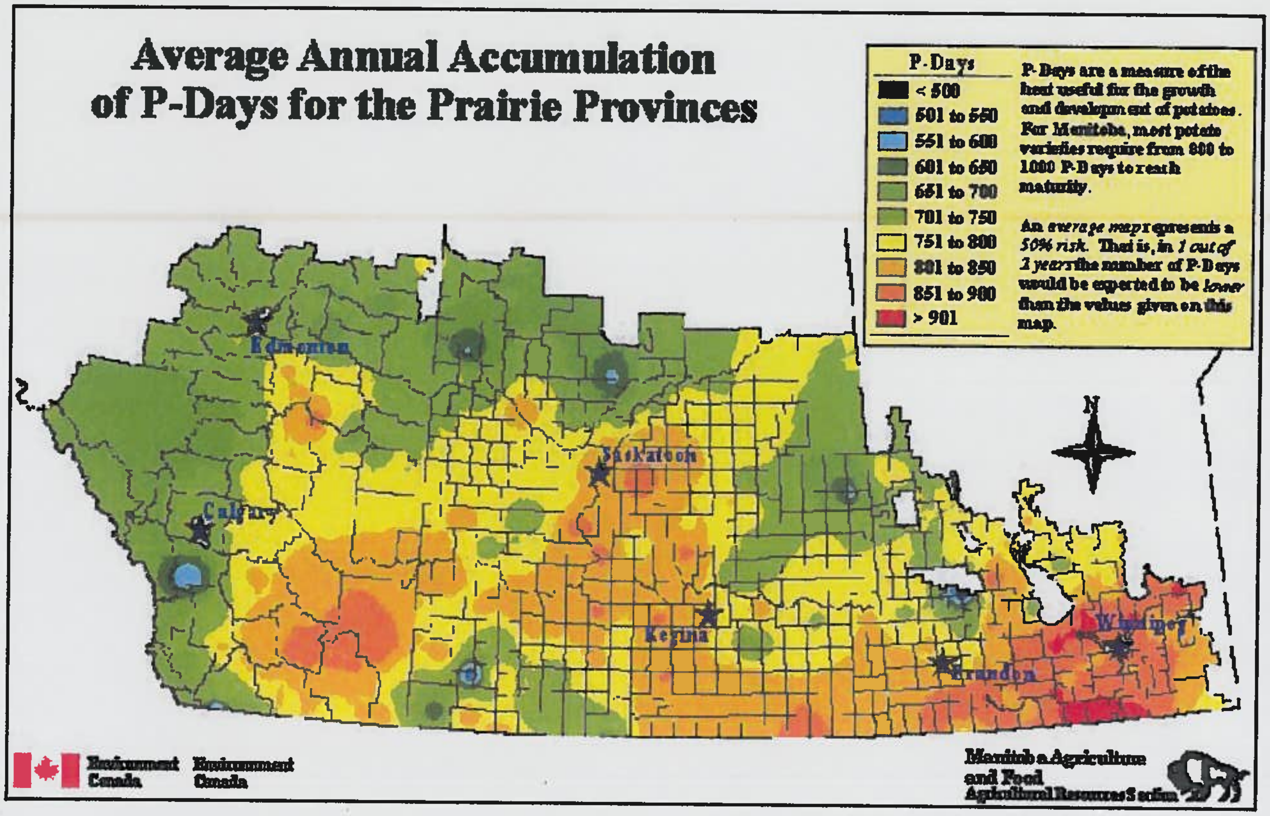


Plate 1. Average annual Physiological Days (P-Days) for the Prairie Provinces. (Courtesy of Manitoba Agriculture and Food)

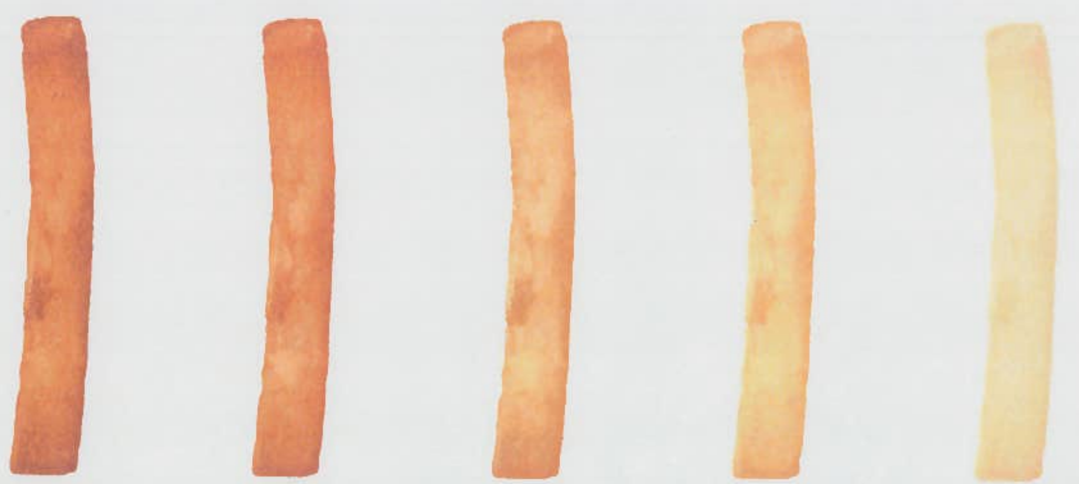


Plate 2. USDA French fry color chart.