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Reflectance Differences Between Target and Torch Rape Cultivars[1]

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ABSTRACT

To characterize and explain leaf and plant reflectance differences between Target (*Brassica napus* L.) and Torch (*Brassica campestris* L.) rape cultivars, laboratory spectrophotometric reflectance measurements were made on leaves of the same age, collected from different nodes, and on leaves of different ages, collected from the same node, for both small (five leaves) and large (nine leaves) Target and Torch plants. Spectroradiometric reflectance measurements were made on Target and Torch plants (four and five leaves, respectively) that were growing in 0.09 m² soil-containing flats. Torch's spectrophotometric single leaf reflectance was consistently lower than Target's at the 650-nm chlorophyll absorption band because Torch's chlorophyll concentration was larger than Target's, which caused more red light absorptance. Spectroradiometric measurements indicated that: (1) wet soil strongly absorbed visible light (500 to 700 nm) so that Target's soil-containing flat with 60% plant cover had less reflectance than Torch's soil-containing flat with 75% plant cover, (2) Torch (most foliage) had higher near-infrared (750 to 1,350 nm) reflectance than Target (least foliage), and (3) the 2,200-nm wavelength is a candidate band to distinguish Target from Torch. The difference in chlorophyll concentrations between Target and Torch, compared with leaf structural differences, is apparently the most important factor that would affect the infrared color film's tonal response to vegetation in the photographic sensitive region (500 to 900 nm).

Additional index words: Spectrophotometer, Chlorophyll, Soil, Leaf structure, Infrared color film, Remote sensing.

TARGET (*Brassica napus* L.) and Torch (*Brassica campestris* L.) rape cultivars have been distinguished with color-infrared aerial photography in Canadian remote sensing-crop identification programs (Mack and Bowren, 1975). This unexpected result emphasized the need for basic information on rape's leaf and plant reflectance. Large variations in reflectance can result because of differences in growth stages and physiological characteristics of exposed leaves (Hoffer and Johannsen, 1969; Knipling, 1970; Gausman et al., 1973a; Woolley, 1971; Wiegand et al., 1972; Sinclair et al., 1973). Consequently, we undertook this study to characterize and explain leaf and plant reflectance differences between the Target and Torch rape cultivars.

MATERIALS AND METHODS

Target and Torch rape cultivars were selected for study, representing Argentine summer rape and Polish turnip rape, respectively.

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Rape seeds were planted at two different times (Experiment 1 in January 1975; Experiment 2 in March 1975) in a greenhouse: a randomized complete block experimental design with 18 replications of the two cultivars was used for each experiment. However, all seeds did not germinate and difficulty was encountered with the cabbage looper [*Autographa brassicae* (Riley)]. Consequently, as indicated later, numbers of replications varied for leaf reflectance and physical measurements.

For each experiment, four rape seeds were planted in each 4.0-liter plastic pot containing a mixture of sandy clay loam soil, Perlite[a] (a horticulture conditioner; 0.02% by weight), and a 10-25-5 fertilizer to give an equivalent rate of 67 kg N/ha. Plants were thinned to two per pot 9 and 10 days after emergence for Experiment 1 and 2, respectively. One plant was designated for comparisons of reflectance measurements on leaves of the same chronological age (Target vs. Torch); the leaves compared thus came from different nodes. The other plant was designated for comparisons of reflectance measurements on leaves from the same node (Target vs. Torch); the leaves compared thus differed in chronological age.

Small plants (five leaves) were used 19 days after emergence in Experiment 1. Target's and Torch's leaves of the same age (15 days old) were collected from nodes 2 and 3, respectively, for 16 replications. Target's and Torch's leaves of different ages (14 and 16 days, respectively) came from node 1 from 16 replications. These leaf collecting procedures are generally referred to as: (1) leaves of the same age from different nodes of small plants, and (2) leaves of different ages from the same node of small plants.

Larger plants (nine leaves) were used 40 days after emergence in Experiment 2. Target's and Torch's leaves of the same age (32 days old) were collected from nodes 3 and 5, respectively, for 15 replications (nodes were counted from the base of a plant.) Target's and Torch's leaves of different ages (22 and 27 days, respectively) came from node 6 and 10 replications. These leaf collecting procedures will be generally referred to as: (1) leaves of the same age from different nodes of large plants, and (2) leaves of different ages from the same node of large plants.

Immediately after leaves were collected, they were wrapped in plastic wrap and stored on ice to minimize water loss. In the laboratory, leaves were cut in half longitudinally; one half was used for spectral and physical measurements and one half was used for chlorophyll analysis. Leaf thickness was measured with a linear-displacement transducer and digital voltmeter (Heilman et al., 1968). Leaf area was determined with a planimeter. Water content of leaves was determined on a dry-weight basis; leaves were oven dried at 68 C for 72 hours and cooled in a desiccator before weighing.

Tissue pieces sampled from the center of leaves were fixed in formalin-acetic acid-alcohol, dehydrated with a tertiary butanol series, embedded in paraffin, stained with the safranin-fast green combination, and transversally microtomed at 12-μm thickness (Jensen, 1962). Photomicrographs were obtained with a Zeiss Standard Universal Photomicroscope.

A Beckman Model DK-2A spectrophotometer, equipped with a reflectance attachment, was used to measure total diffuse reflectance on upper (adaxial) surfaces of single leaves over the 500- to 2,500-nm waveband. Data were corrected for decay of the barium sulfate standard (Allen and Richardson, 1971) to give absolute radiometric data. All tissue sampling and measurement procedures were completed within 7.5 hours of leaf collection.

Seven wavelengths were selected from the 41 wavelengths measured at 50-nm increments over the 500- to 2,500-nm waveband. Wavelengths selected were 550, 650, 850, 1,450, 1,650, 1,950, and 2,200 nm; representing, respectively, the green reflectance peak, chlorophyll absorption band, a wavelength on the near-infrared plateau, the 1,450-nm water absorption band, the 1,650-nm peak following the 1,450-nm water-absorption band, the 1,950-nm water-absorption band, and the 2,200-nm peak following the 1,950-nm water-absorption band.

The t test (Steel and Torrie, 1960) was used to statistically test the difference between means of Target's and Torch's leaves for reflectance data at each of the seven wavelengths and for

Table 1. Average characteristics of Target and Torch rape leaves of the same age and different ages collected from both small and large plants.

Rapeseed cultivar	Water content	Leaf thickness	Leaf area
	%	mm	cm^2
Leaves of same age from different nodes of small plants			
Target	89.5	0.16	18.5
Torch	88.9	0.16	19.5
Difference	0.6	0.0	−1.0
Leaves of different ages from same node of small plants			
Target	89.7	0.19	10.3
Torch	90.5	0.18	7.2
Difference	−0.8	0.01	3.1*
Leaves of same age from different nodes of large plants			
Target	90.6	0.27	126.7
Torch	90.5	0.23	139.0
Difference	0.1	0.04*	−12.3
Leaves of different ages from same node of large plants			
Target	88.7	0.22	188.9
Torch	91.4	0.21	142.4
Difference	−2.7*	0.01	46.5*

* Denotes significant difference at the 5% probability level.

leaf water content, thickness, and area data. Total chlorophyll was determined by a routine method (Horwitz, 1965) on leaf samples stored 97 days at −15 ± 5 C.

Spectroradiometric measurements were made on the cultivars grown in 0.09 m^2 soil-containing flats to simulate field conditions. Fifty seeds for each cultivar were planted per flat. However, unequal germination resulted in 40 and 50 plants per 0.09 m^2 area for Target and Torch, respectively. Ground cover at the time of measurement was about 60% for Target's four-leaf plants and 75% for Torch's five-leaf plants. An Exotech Model 20 spectroradiometer (Leamer et al., 1973) was used to measure reflected radiation over the 500- to 2,500-nm waveband. Measurements were made 0.9 m above the plants with a 15° field view (0.044 m^2).

RESULTS AND DISCUSSION

Leaf Physical Measurements

Water contents of Target's and Torch's leaves were not significantly different ($p = 0.05$) with the exception of leaves of different ages that were collected from the same node of large plants (Table 1). Target's leaves were thicker than Torch's only when leaves of the same age were collected from different nodes of large plants. Target's leaves were larger (upper surface area per leaf) when leaves of different ages were collected from the same node of both small and large plants.

Laboratory Spectrophotometric Measurements

Photographically sensitive visible and near-infrared region. The 500- to 900-nm waveband essentially encompasses the sensitivity range of both conventional and infrared color film (when a yellow filter is used to absorb blue light). Conventional color film is sensitive to visible light, and infrared color film with a yellow filter is sensitive to light from the 500-nm wavelength in the visible region up to about the 900-nm wavelength in the near-infrared region (Fritz, 1967).

Three important wavelengths within the 500- to 900-nm photographically sensitive region are shown in Table 2: (1) 550-nm wavelength (green reflectance peak), (2) 650-nm wavelength (chlorophyll absorption

[a] Mention of a company name or trademark is for the readers' benefit and does not constitute endorsement of a particular product by the U.S. Department of Agriculture over others that may be commercially available.

band), and (3) 850-nm wavelength, a candidate band for discriminating purposes in the reflective near-infrared region (Gausman et al., 1973b).

Leaf reflectance differences between the Target and Torch rape cultivars were statistically significant ($p = 0.05$) for the 650-nm wavelength at all times that leaves were collected. Target's leaf reflectances were higher than Torch's because Target had a lower average total chlorophyll concentration (09.06 mg/g) than Torch (10.22 mg/g). Thus, Torch's leaves had more red light absorptance than Target's leaves. Reflectance at the 550-nm wavelength (green peak) was significantly different only when leaves of different ages were collected from the same node of small plants.

Healthy foliage records red on infrared color film because a light-toned cyan image (less dense or less saturated) results, which allows the transmittance of more red radiation in the viewing (Gausman et al., 1970a). High chlorophyll (Torch) would increase red light absorptance, decrease its reflectance (less red radiation impinging on the film), and cause a more saturated image in the infrared color film's magenta dye layer. Thus Torch leaves, with their higher chlorophyll concentration, appeared darker red on the transparency, as reported by Mack and Bowren (1975), than did Target's leaves, which had a lower chlorophyll concentration.

Reflectance of a plant leaf has been explained on the basis of critical reflection of light at the cell wall-air interface of the spongy mesophyll tissue (Willstätter and Stoll, 1918). Near-infrared light reflectance (750 to 1,350 nm) usually increases with an increase in number of intercellular air spaces (Gausman et al., 1970) because light is scattered in passing from intercellular air with a refractive index of 1.0 to hydrated cell walls with a refractive index of 1.425 (Gausman et al., 1974).

Reflectances at the 850-nm wavelength were not significantly different when leaves of the same age were collected from different nodes of either small or large plants. However, Target's reflectances were larger than Torch's when leaves of different ages from the same node were compared from either small or large plants.

Target's and Torch's leaf transections were compared. Their mesophylls were similar when their leaves were the same chronological age. This was expected because reflectance differences between them were not significant at the 850-nm near-infrared wavelength for leaves of the same age from either small or large plants (Table 2). The effects of leaf age differences on mesophyll structure and near-infrared light reflectance have been previously described (Gausman et al., 1970b).

Water Absorptance Near-Infrared Region

Target's leaves had less reflectance than Torch's leaves at both water absorption bands (1,450 and 1,950 nm) for leaves of the same and different ages from small plants (Table 2). However, Target's leaf water contents were not much different from Torch's (Table 1). Moreover, coefficients for linear correlations of leaf reflectances with their respective water contents were statistically significant but extremely low (−0.24 to −0.45) at either the 1,450- or 1,950-nm wavelengths.

Spectral wavelength intervals centered around the 1,650- and 2,200-nm wavelengths may provide for optimum discrimination of vegetation (Gausman et al., 1978). Torch's leaf reflectance were higher than Target's for all measurements (Table 2) except for leaves of different ages from large plants at the 1,650- and 2,200-nm wavelengths.

Spectroradiometric Measurements

Plant density, soil water content, and leaf color affected spectroradiometric measurements made on Target and Torch plants that were grown in soil-containing flats (Fig. 1). Although equal numbers of seeds were planted for each cultivar, seedling emergence di[illegible]

Table 2. Average leaf reflectances at seven wavelengths of Target and Torch rape leaves of the same age and different ages collected from both small and large plants.

Rapeseed cultivar	Average leaf reflectance						
	550nm	650nm	850nm	1,450nm	1,650nm	1,950nm	2,200nm
	%						
Leaves of same age from different nodes of small plants							
Target	14.9	8.8	41.6	12.0	27.0	3.9	13.9
Torch	15.7	8.0	41.0	13.2	28.4	4.7	15.8
Difference	−0.8	0.8*	0.6	−1.2*	−1.4*	−0.8*	−1.9*
Leaves of different ages from same node of small plants							
Target	15.3	8.9	41.6	9.9	25.1	3.6	11.8
Torch	16.4	8.3	40.4	10.8	26.3	3.9	13.4
Difference	−1.1*	0.6*	1.2*	−0.9*	1.2*	−0.3*	−1.6*
Leaves of same age from different nodes of large plants							
Target	14.4	8.8	44.6	9.0	25.0	3.6	10.9
Torch	13.9	7.5	43.5	10.4	27.2	3.5	13.1
Difference	0.5	1.3*	1.1	−1.4	−2.2*	0.1	−2.2*
Leaves of different ages from same node of large plants							
Target	14.8	10.1	46.8	11.6	28.4	4.4	14.0
Torch	14.2	8.3	44.2	11.5	28.0	4.0	14.0
Difference	0.6	1.8*	2.6*	0.1	0.4	0.4	0.0

* Denotes significant difference at the 5% probability level.

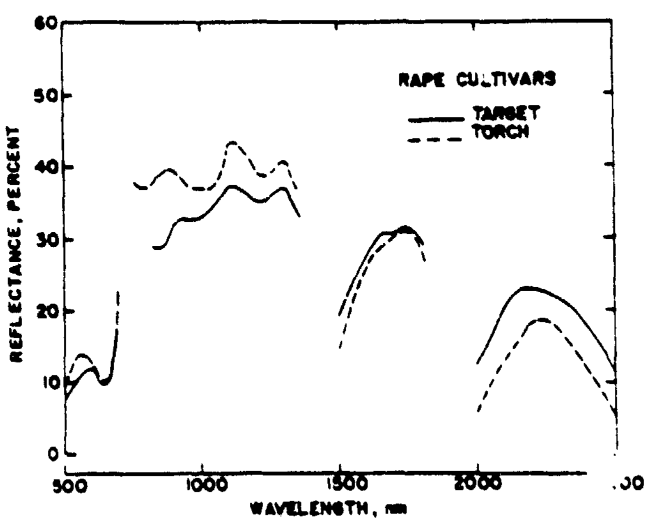

Fig. 1. Spectroradiometrically measured reflectance over the 500 to 2,500-nm waveband for plants of the Target and Torch rape cultivars in soil-containing flats.

fered. Final plant densities were 40 and 50 plants/ 0.09 m^2 for Target and Torch, respectively.

Torch's reflectance was higher than Target's within the 500- to 750-nm waveband. We immediately deduced that the opposite should have been true, because Torch's plant density was higher and its leaves were greener than Target's. Consequently, Torch would have more absorptance of red light and less reflectance of green light than Target. However, water was added to the soils to ensure turgid plants at the time of measurement. Wet soils, compared with dry soils, strongly absorb visible light (Hoffer and Johannsen, 1969). Thus, Target's soil background absorbed more light (less reflectance) than Torch's. Apparently, this soil background effect was too strong for the leaf color differences to manifest themselves.

Torch's plant density was higher than Target's, causing higher reflectance from Torch over the 750- to 1,350-nm reflective near-infrared region (Fig. 1). Reflectance for this waveband may increase with an increase in leaf area index, plant population, plant height, or percent plant cover (Wiegand et al., 1974).

Target's and Torch's reflectance were essentially the same over the 1500- to 1,950-nm waveband in the near-infrared water absorptance region. Over the 2,000- to 2,500-nm waveband, however, Target's reflectance was higher than Torch's. Therefore, we can speculate that the flats containing a high density (75%) of Torch plants somehow had more water exposed to the sensor than did the flats with the lower density (60%) of Target plants.

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