EXAMINING THE FRUIT RIPENING STAGES USING DIGITAL PHOTOGRAPHIC TECHNIQUE

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ABSTRACT: The wild blueberry industry may benefit significantly from precision agriculture technology. Northeastern North America is the world’s leading producer of wild blueberry (Vaccinium angustifolium Ait.), producing 148.77 million kg of berries and contributing $196.74 million annually to the provincial and federal economies. Ripening of wild blueberry at the time of harvest is the leading factor for final fruit quality. Currently, there are no protocols available for the farming community related to wild blueberry fruit ripening and maturity. Two wild blueberry fields were selected in Atlantic Provinces to examine the berry ripening levels using digital photographic technique on different harvesting times (early, middle and late). The field was divided into four blocks and each block was further divided into three classes of early, middle and late. Fruit images from each block at early, middle and late seasons were acquired and processed to count blue pixels from each image, using image processing software.
A significant correlation was found between the percentage of blue pixels and actual fruit yield in Field A (R2 = 0.96; P < 0.001) and Field B (R2 = 0.97; P < 0.001). The correlation between actual and predicted fruit yield in both fields was also highly significant. The absolute and relative measures further strengthened the model. The results also indicated that the effect of time of harvesting on blue pixels/wild blueberry yield was significant and blue pixels/blueberry yield
increased gradually during early harvesting, reached maximum in late harvesting and then started to decrease in late harvesting. Comparison results indicated that 90% of green berries turned blue at the end of middle season compared to early season (58%).

**Keywords:** Blueberry, digital photographic technique, precision agriculture,

**INTRODUCTION:** The importance of nondestructive and noninvasive computerized digital image analysis that can process and analyze information from images is acknowledged by several researchers (Richardson et al., 2001; Díaz-Lago et al., 2003; Karcher and Richardson, 2003). Steddom et al. (2004) explained the attractiveness of this method is, its low cost cameras, computers and software packages at present time. Lukina et al. (1999) employed digital image processing technique to calculate percent coverage and biomass of wheat using digital color, Red-Green-Blue (RGB), images on crop canopies. Mirik et al. (2006) evaluated the importance of digital image analysis technique to quantify damage caused by green bugs on winter wheat. Richardson et al. (2007) concluded that phonological changes in canopy state of spring green-up in deciduous broadleaf forest can be quantified using digital webcam images. Furthermore, they also suggested that this technique can be used for regional or national phonological monitoring program. Mendoza and Aguilera (2004) investigated different ripening stages of bananas by acquiring images using computer vision system and characterized changes in color quantitatively. They further related brown spots and textural features of images with ripening stages.

Similar studies for fruit detection were conducted for apple, citrus and tomatoes. Numerous researchers used computer image analysis techniques (also known as computer vision system), that encounter the deficiencies of visual and instrumental techniques very well and give a complete measure for color and other physical factors (Paulus and Schrevens, 1999; Shahin and Symons, 2001; Chen et al., 2002). Digital color camera and image processing software is more comprehensive and inexpensive method to investigate color of many foods over traditional color measuring instruments (Yam and Papadakis, 2004). Parrish and Goksel (1977) used a method based on pictorial pattern recognition and artificial intelligence techniques for feasibility of apple harvesting. Whittaker et al. (1987) used fruit shape instead of color information for tomato detection non-destructively. Slaughter and Harrell (1987) developed an image based on color information system for orange fruit detection.

A number of researchers used digital photography technique to estimate fruit yield in wild blueberry fields (Zaman et al., 2008; Chang et al., 2012; Farooque et al., 2013). Zaman et al. (2008) used a cost effective 10 megapixel digital color camera, acquired wild blueberry images, calculated blue pixels from the images and correlated blue pixel ratios with manually harvested actual fruit yield from selected points within wild blueberry fields. The digital photography techniques have been extensively used to estimate fruit yield for many cropping systems, however, its application to assess the ripening stages of the fruit have been very limited. This study encompass the potential of digital photography techniques in predicting the ripening stages of fruit at different times during harvesting. In this study, digital color photographic technique using blue-green-pixel (BGP) ratio was used to examine fruit ripening stages for wild blueberry crop.

**Material and Methods:** Two wild blueberry fields were selected in central Nova Scotia to evaluate a photographic method for examining fruit ripening. The selected fields were East Mine-II (Field A) (45.43°N, 63.48°W; 3.66 ha) and Highland Village-II (Field B) (45.24°N, 63.40°W; 1.04 ha). Both fields were in crop year of the biennial production cycle in 2015. The selected fields had been under commercial management receiving biennial pruning by mowing for the past several years along with conventional pest, disease and weed control management practices. Completely randomized block design was used at each field. The selected fields were divided into four blocks and each block was further divided into three levels of harvesting season randomly. Sixty sampling points within four blocks were selected in each field to cover overall variability in fruit ripening. The
experimental blocks, sampling points and field boundaries were marked using a Real Time Kinematics Global Positioning System (RTK-GPS). The mapped data was imported in ArcView 10.1 Geographical Information System (GIS) (ESRI, Redlands, CA, USA) software for visual display. A 0.5 m × 0.5 m (0.25 m²) wooden frame quadrat was constructed and placed at selected sampling points in both fields to define the area of interest in the image. A 16 megapixel 24-bit digital color camera (Fujifilm Canada, Inc., Mississauga, ON, Canada) was used to take photographs of the blueberry fruit from a height of about 0.5-1.0 m. Starting from early until the end of harvesting season, blueberry fruit images were collected at specified locations in each block within the selected fields. The image exposure and other camera settings were set automatically for this experiment. The images were imported into a computer for further processing. A custom image processing software developed in C++ using Visual studio 2008 (Microsoft, Redmond, WA, USA) was used to estimate the percentage of blue pixels representing ripe fruit in the field of view. The software was used to enhance and count the blue pixels in the quadrat region of each image, using RGB pixel ratio, and expressing the results as a percentage of total quadrat pixels. The used ratio was \( \frac{(B \times 255)}{(R+G+B)} \) and a manually attained threshold (>80) effectively differentiated the apparent blue fruit pixels from remaining pixels in all images. Image analysis was confined to the quadrat by defining a rectangular polygon bounding region corresponding to the quadrat outline in the image and this was achieved by masking out the image. Small clusters of pixels in the image were incorrectly identified as fruit due to specular reflection and deep shadows, but these were easily removed by applying one pass of an erosion filter. The final result of percentage of blue pixels in the quadrat region of each image was calculated automatically by running the software in batch mode and results were added to a comma-separated values (csv) file format. The blue pixels after calibration equation/model represent ripe fruit yield. So, we used blue pixels/ wild blueberry fruit throughout our discussion.

**Manual Fruit Yield Measurement:** The same 0.5 m × 0.5 m wooden quadrat frame, used for acquiring images, was used to collect the fruit yield samples in early, middle and late season from each block in both fields. The fruit samples were harvested manually using hand rake and only ripe blueberries were included in the samples. Blueberries were separated from debris including grass, leaves and weeds for each sample.

**Statistical Analysis:** Linear regression was used to calibrate actual ripe fruit yield with percentage blue pixels separately in each field. The calibration equation of Field A was used to predict fruit yield in Field B and calibration equation of Field B was used to predict fruit yield in Field A for validation. Calibration and validation equations/models, R² and RMSE were calculated in Minitab 17 (Minitab Inc., PA, USA). MAE, E, EM, EMP, d, dM, dMP were calculated using Microsoft Access (Microsoft Corp., Seattle, WA, USA). Analysis of variance (ANOVA) was used to evaluate the ripening of fruit at different stages of harvesting (early, middle and late) using Minitab. The ripening of fruit was examined by calculating the percentage blue pixels at selected sampling locations. Normal probability plot of residuals using Anderson-Darling (AD) test at significance level of 5% was used to check the normality of the error terms. Residual versus fits plot was used to check the constant variance. The deviation from normality and constant variance assumptions required suitable transformation on collected data. Independence of error terms was achieved by applying treatments randomly. ANOVA using general linear model (GLM) procedure was utilized to examine the fruit ripening at different harvesting times. Multiple means comparison (MMC) was performed using honestly significant difference (HSD) to determine which specific means significantly differ from each other in early, middle and late season.

**Results and Discussion:** The custom image processing software was used to calculate and express the percentage of blue pixels in the quadrat region of the image in both fields. The zero percentages of blue pixels were due to the presence of greener berries (not ripened or absence of blue berries) within the selected blocks of wild blueberry fields. Images were also acquired, when
all berries were green. The percentage of blue pixels significantly correlated the manually harvested yield in Field A (R² = 0.96; P < 0.001) and Field B (R² = 0.95; P < 0.001) (Fig. 1).

Figure 1. Calibration curve between percentage of blue pixels and actual fruit yield for (a) Field A and (b) Field B.

A slight deviation in mean values can be seen in both scatter plots, suggesting fruit yield was under or over-estimated. A dense vegetation and hidden berries under leaves might be the reason of under-estimation. In addition, under-estimation could also be related to overlays (in a bunch, accompanying a few pixels in the image), which arose in high yielding areas. Less or negligible vegetation and berries exposed to the camera could be the result of over-estimation. The correlation between actual and predicted fruit yield in Field A (validated using the equation of Field B) and Field B (validated using the equation of Field A) was also highly significant.

**Statistical Results:** ANOVA results revealed that the effect of time of harvesting on blue pixels/wild blueberry yield was significant, but the effect of the blocks was non-significant with each other in Fields A and B. The results of MMC indicated that blue pixels/wild blueberry yield increased gradually in early harvesting and reached a maximum in late harvesting and then started decreasing in late harvesting in Field A (Table 1). The blue pixels/blueberry yield was non-significant to each other on imaging dates (14/7/15 and 17/7/15) and (17/7/15 and 20/7/15) during early season harvesting with an increase of 3 and 4 g 0.25 m⁻², respectively, in Field A. The blue pixels/blueberry yield increased significantly by 29%, 30% and 35% between imaging dates
(23/7/15 and 26/7/15), (26/7/15 and 29/7/15) and (29/7/15 and 1/8/15), respectively, in early season (Table 1). Similarly, the blue pixels/blueberry yield was found to be significant with an increase of 16%, 24% and 20% between dates (4/8/15 and 7/8/15), (7/8/15 and 10/8/15) and (10/8/15 and 13/8/15), respectively during early season in Field A. A significant increase in blue pixels/blueberry yield continued in middle season with 13%, 10% and 9% increments between the dates (16/8/15 and 19/8/15), (19/8/15 and 22/8/15) and (22/8/15 and 25/8/15) in Field A (Table 1). The blue pixels/blueberry yield increased, but non-significantly, between the first two dates (28/8/15 and 31/8/15) in late season. The decreasing trend in blue pixels/blueberry yield started at 3/9/15 in late season. The blue pixels/blueberry yield decreased significantly between dates (31/8/15 and 3/9/15), (3/9/15 and 6/9/15) and (6/9/15 and 9/9/15) with 3%, 4% and 7% decrement in late season, respectively. The decline in blue pixels/blueberry yield might be the result of ripe blueberries dropping from the plants in late season. A considerable increase in blue pixels/blueberry yield of 746% and 35% were observed in early and middle season, respectively, whereas a 14% decrease was also noticed in late season in Field A.

Table 1. Results of MMC of blue pixels/wild blueberry yield in both fields.

<table>
<thead>
<tr>
<th>Imaging Date</th>
<th>Harvesting Time</th>
<th>Blueberry Yield (g 0.25 m²) Field A</th>
<th>Blueberry Yield (g 0.25 m²) Field B</th>
</tr>
</thead>
<tbody>
<tr>
<td>14/7/15</td>
<td>Early</td>
<td>18.67 q</td>
<td>23.84 p</td>
</tr>
<tr>
<td>17/7/15</td>
<td>Early</td>
<td>22.08 pq</td>
<td>27.38 p</td>
</tr>
<tr>
<td>20/7/15</td>
<td>Early</td>
<td>26.14 p</td>
<td>36.52 o</td>
</tr>
<tr>
<td>23/7/15</td>
<td>Early</td>
<td>31.55 o</td>
<td>49.09 n</td>
</tr>
<tr>
<td>26/7/15</td>
<td>Early</td>
<td>40.78 n</td>
<td>63.97 m</td>
</tr>
<tr>
<td>29/7/15</td>
<td>Early</td>
<td>53.10 m</td>
<td>89.05 l</td>
</tr>
<tr>
<td>1/8/15</td>
<td>Early</td>
<td>71.76 l</td>
<td>101.86 k</td>
</tr>
<tr>
<td>4/8/15</td>
<td>Early</td>
<td>91.20 k</td>
<td>115.73 j</td>
</tr>
<tr>
<td>7/8/15</td>
<td>Early</td>
<td>106.30 j</td>
<td>135.78 i</td>
</tr>
<tr>
<td>10/8/15</td>
<td>Early</td>
<td>131.75 i</td>
<td>149.42 h</td>
</tr>
<tr>
<td>13/8/15</td>
<td>Early</td>
<td>157.92 h</td>
<td>164.79 g</td>
</tr>
<tr>
<td>16/8/15</td>
<td>Middle</td>
<td>180.36 g</td>
<td>178.99 f</td>
</tr>
<tr>
<td>19/8/15</td>
<td>Middle</td>
<td>203.43 f</td>
<td>193.39 e</td>
</tr>
<tr>
<td>22/8/15</td>
<td>Middle</td>
<td>223.32 d</td>
<td>217.95 c</td>
</tr>
<tr>
<td>25/8/15</td>
<td>Middle</td>
<td>244.14 b</td>
<td>230.66 a</td>
</tr>
<tr>
<td>28/8/15</td>
<td>Late</td>
<td>249.13 a</td>
<td>231.08 a</td>
</tr>
<tr>
<td>31/8/15</td>
<td>Late</td>
<td>251.16 a</td>
<td>228.96 ab</td>
</tr>
<tr>
<td>3/9/15</td>
<td>Late</td>
<td>243.95 e</td>
<td>222.05 bc</td>
</tr>
<tr>
<td>6/9/15</td>
<td>Late</td>
<td>233.12 c</td>
<td>207.76 d</td>
</tr>
<tr>
<td>9/9/15</td>
<td>Late</td>
<td>215.77 e</td>
<td>196.21 e</td>
</tr>
</tbody>
</table>

Means that do not share a letter are statistically non-significant from each other (Tukey’s HSD, p ≤ 0.05).

A similar trend of increase and then decrease in blue pixels/blueberry yield was also noticed in Field B. An increase in blue pixels/blueberry yield was non-significant between the first two dates (14/7/15 and 17/7/15) during early season in Field B (Table 1). The increase in blue pixels/blueberry yield was found to be significant, with 34%, 30%, 39% and 14% increments between the dates (20/7/15 and 23/7/15), (23/7/15 and 26/7/15), (26/7/15 and 29/7/15) and (29/7/15 and 1/8/15) in early season, respectively. The increasing trend in blue pixels/blueberry yield continued significantly, with an increase of 17%, 10% and 10% between the dates (4/8/15 and 7/8/15), (7/8/15 and 10/8/15) and (10/8/15 and 13/8/15), respectively, during early season in Field B (Table 1). A significant rise in blue pixels/blueberry yield was observed between the dates (16/8/15 and 19/8/15), (19/8/15 and 22/8/15) and (22/8/15 and 25/8/15) with an increment of 8%, 13% and 6% in middle season, respectively. A non-significant increase in blue pixels/blueberry yield was
noticed on 28/8/15 of late season. A declining trend in blue pixels/blueberry yield was seen between the dates (28/8/15 and 31/8/15) and (31/8/15 and 3/9/15), with non-significant decrement during late season in Field B. A significant decrease in blue pixels/blueberry yield, with 6% and 6% decrements between the dates (3/9/15 and 6/9/15) and (6/9/15 and 9/9/15) was depicted during late season in Field B, respectively (Table 1). Overall, a 591% and 29% increase in blue pixels/blueberry yield was seen in early and middle season, respectively, whereas a 15% decrease was also observed during late season in Field B.

A similar trend in blue pixels/blueberry yield, starting with the lowest magnitude, reaching the highest level and then declining in magnitude, was found in Fields A and B. A difference in the initial magnitude of 5.17 g 0.25 m$^{-2}$ suggested that there were maturity differences between Fields A and B. An overall increase of 232.49 g 0.25 m$^{-2}$ and 207.24 g 0.25 m$^{-2}$ and a decrease of 35.39 g 0.25 m$^{-2}$ and 34.87 g 0.25 m$^{-2}$ in blue pixels/wild blueberry yield was observed in Fields A and B, respectively (Table 1). An increase in blue pixels/ blueberry yield was the outcome of green berries ripening, while a decrease was the consequence of berries dropping from plants due to microbial attack or decay in late season.

The comparison between blue and green berries at different harvesting times: The comparison between the number (no.) of green and blue berries revealed that green berries converted into blue gradually with passage of time. The number of green berries were dominant in early season and less than 10% blue berries were seen from 14/7/15 to 20/7/15 in Field A (Fig. 2). The berries gradually turned blue, with an increase of 30% from harvesting dates 23/7/15 to 7/8/15 during early season in Field A. The greatest increase in blue berries of 11% and 7% were observed between harvesting dates (7/8/15 and 10/8/15) and (10/8/15 and 13/8/15) during early season, respectively. The conversion of greener to blue berries continued, with an increase of 8% and 7% between the harvesting dates (16/8/15 and 19/8/15) and (19/8/15 and 22/8/15), respectively, during middle season in Field A (Fig. 2). A total of 85% greener berries turned into blue by the end of middle season harvesting in Field A. A green berries of 6% converted into blue berries from the harvesting date 28/8/15 to 3/9/15 in late season. There were still around 5% green berries at the termination of the experiment in Field A. The reason could be that some of the blueberries did not receive adequate pollination or had fewer viable seeds. Aalders and Hall (1961) reported that every blueberry fruit should have at least 6 to 10 viable seeds and where there are less than 6 seeds, the fruit may remain small or unripe.

![Figure 2: Comparison of green and blueberries at different harvesting dates in Field A.](image-url)
The number of blue berries were found less than 10% for the first two harvesting dates 14/7/15 and 17/7/15 of early season harvesting in Field B (Fig. 3). The trend of increasing blue and decreasing green berries continued from 20/7/15 to 4/7/15 with an addition of 30% blue berries during early season harvesting in Field B. The number of blue berries were of 50%, 56% and 60% at harvesting dates 7/8/15, 10/8/15 and 13/8/15, respectively, in early season harvesting in Field B. Since 40% of the berries were still green at the end of early season harvesting in Field B, early season harvesting would not be a wise decision. An increase of 5% in blue berries was observed between harvesting dates 16/8/15 and 19/8/15 in middle season in Field B (Fig. 3).

A dramatic increase in blue berries was detected between the harvesting dates (19/8/15 and 22/8/15) and (22/8/15 and 25/8/15), with an increase of 10% and 7% during middle season in Field B, respectively (Fig. 3). Results showed that approximately 90% of green berries turned blue at the end of middle season in Field B. A very small number of berries, around 5%, became blue in late season. There were still around 5% green berries at the termination of the experiment in Field B. An overall of 40%, 10% and 5% green berries were present at the end of early, middle and late season in Field B, respectively.

**Comparison between manually harvested (g 0.25 m\(^{-2}\)) and no. of blueberries**

Results of comparison between manually harvested and no. of blueberries showed that manually harvested blueberries increased from 20 g 0.25 m\(^{-2}\) (800 kg ha\(^{-1}\)) to 45 g 0.25 m\(^{-2}\) (1800 kg ha\(^{-1}\)), while the no. of blueberries increased from 35 to 65 from harvesting dates 14/7/15 to 26/7/15 in early season in Field A. The manually harvested blueberries increased by 100 g and no. of blueberries rose by 135 from 29/7/15 to 13/8/15 in early season harvesting (Fig. 4). Manually harvested blueberries started with around 180 g 0.25 m\(^{-2}\) (7200 kg ha\(^{-1}\)) and ended at 245 g 0.25 m\(^{-2}\) (9800 kg ha\(^{-1}\)) and no. of blueberries increased from 250 to 320 from 16/8/15 to 25/8/15 during middle season in Field A. The highest no. of blueberries, 330, and harvested berries, 250 g 0.25 m\(^{-2}\) (10000 kg ha\(^{-1}\)), were found on the harvesting date 31/8/15 in late season (Fig. 4). The decline in harvested and no. of blueberries were 30 g and 50, respectively, from 31/8/15 to 9/9/15 during late season harvesting. The reason of declining blueberries might be the result of microbial attack and berries dropping after decay.

Results indicated that manually harvested blueberries increased from 25 g 0.25 m\(^{-2}\) (1000 kg ha\(^{-1}\)) to 65 g 0.25 m\(^{-2}\) (2600 kg ha\(^{-1}\)), while no. of blueberries increased from 40 to 100 from 14/7/15 to 26/7/15 during early season in Field B (Fig. 5). A gradual increase in harvested blueberries, approximately 74 g, and no. of blueberries, around 87, was observed from harvesting date 29/7/15.

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**Figure 3.** Comparison of green and blue berries at different harvesting dates in Field B.
to 13/8/15 in early season. There were 180 g 0.25 m-2 (7200 kg ha⁻¹) and around 245 blueberries at harvesting date 16/8/15, whereas manually harvested blueberries and no. of blueberries were 230 g 0.25 m-2 (9200 kg ha⁻¹) and 300, respectively, at 25/8/15 during middle season in Field B (Fig. 5). The manually harvested blueberries and no. of blueberries decreased by 35 g and 50, respectively, from 31/8/15 to 9/9/15 in late season harvesting in Field B.
CONCLUSION This study was conducted with an aim to evaluate the performance of digital photography technique to estimate blueberry ripening and yield at different harvesting times. There was a significant correlation between the percentage of blue pixels and actual fruit yield in Field A ($R^2 = 0.96; P < 0.001$) and Field B ($R^2 = 0.97; P < 0.001$). The correlation between actual and predicted fruit yield (validation) in Field A and B was also highly significant. The absolute measures of RMSE and MAE showed strong correlation between actual and predicted fruit yield. The relative performance measures of coefficient of efficiency and index of agreement further strengthened the model performance. The modified measures were lower than those of the unmodified. The results indicated that the modified versions use higher standards of model performance and differences between EM and EMP and between dM and dMP express the sensitiveness of model performance to outliers for different harvesting times. The results also indicated that the effect of time of harvesting on blue pixels/wild blueberry yield was significant and blue pixels/wild blueberry yield increased gradually during early harvesting, reached maximum in late harvesting and then started to decrease in late harvesting. Comparison results indicated that 90% of green berries turned blue at the end of middle season compared to early season (58%).

It can be concluded that the digital photography is a viable technique to examine ripened blueberry fruit yield and can be used to estimate ripened fruit yield at different harvesting times. This information could be used for timely harvesting decisions in blueberry fields to optimize productivity. It is suggested to include physico-chemical analysis, such as anthocyanin contents, total soluble solids, titratable acidity, moisture contents, weight and diameter should be included as input variables in future studies to examine the ripening of wild blueberries, when dealing with time of harvesting and maturity.

REFERENCES


