

Measuring efficiency of crop cleaners by image analysis

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Abstract: The purity of product from agricultural cleaners (such as chile, cotton, bean, wheat and other crop cleaners) is needed to be measured under various conditions in order to adjust and optimize the machine at the design and improvement stages. The traditional weight-based method of measuring purity is time consuming, and requires much labor. In this study, we used image analysis to measure percent crop cover for the product output to infer the purity. Chile cleaner was used as one example machine to compare between Photoshop© and Arcview© software for the analysis of fresh and dry harvest pictures. The data collection process is more reproducible and less labor and time consuming than the traditional technique. Both software packages provided accurate estimations of purity for both fresh and dry harvest pictures. Photoshop© had better accuracy than Arcview© (mean error ratio of 0.016 vs. 0.081 for fresh harvest; and 0.035 vs. 0.114 for dry harvest).

Keywords: cleaner, measuring efficiency, image analysis, separation, chile, pepper, purity, trash

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1 Introduction

Crop cleaners (such as chile, cotton, bean, wheat and other crop cleaners) at the design and improvement stages need optimal adjustments (different adjustment part type and size) according to the output product purity under various conditions and part combinations. The traditional weight-based method of measuring purity is time consuming, and requires much labor.

For example, scientists at New Mexico State University have been developing a mechanical chile cleaner that removes field trash (leaf and stem) from the

harvested mixture, leaving only pure peppers for future processing^[1]. The machine's output product purity needs to be measured for different harvest mixtures and adjustments to find the optimal adjustment for each mixture. The machine mainly consists of three different stages. After the harvested mixture is inputted to the machine, the first stage separates short trash, the second stage separates the large trash, and the third stage separates the rest trash. The pepper purity in the input and the products at the three stages are needed to be measured. Then various adjustments can be conducted for the three stages to find the optimal one.

Originally, the purity measurements used weight-based methods. The original intent was to weigh each sample in the wet state (moisture content as it came from the field) and then to dry a sub sample to determine a dry weight to convert all weights to a dry weight basis. For each adjustment and pepper condition, six samples of each the input and the product at each stage are needed. That means 24 samples were needed each time. Then the trash and pepper were separated and weighted at the field. Then the pepper percentage in the output based on

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the wet weight was obtained. Sub samples were stored, dried, and weighed at a laboratory. Finally, the dry pepper percentage can be obtained for each sample.

It was quickly determined that the hand sampling and separation was extremely laborious, approximately six to ten minutes per sample with a three-person crew, much more time than was scheduled. For each pepper condition (size and moisture) and each adjustment, about 2 h were spent for the wet-weight based pepper purity measurements for the 24 samples by three person crew. Considering four adjustments for each stage and five different pepper conditions, the total samples would take 640 h by a three-person crew. It was also found that wind and outdoor field conditions greatly degraded the measurement accuracy i.e. cardboard shields had to be erected around the scales to minimize wind buffeting. The only solution was to curtail the number of replications taken, in turn lowering the quality of the overall study.

Then, it was planned to collect samples, bag them, dry them in the sample drier and then separate chile and trash before weighing. This would reduce the sampling crew size, move the separation and weighing processes into a laboratory setting. Unfortunately, the hand bagging proved to be time consuming. Furthermore, each drying procedure took one day and the samples could not be processed in time. Consequently, 15% of the samples were lost in one season.

The weight-based methods are time and labor consuming for purity measurements for products from cleaners. A simple, accurate and convenient method is needed to measure the purity. Imaging analysis was used to evaluate ground cover and crop health as early as 1960^[2]. Image analysis methods are often used to measure crop vegetation cover to determine the biomass growth and were demonstrated accurate^[3-5]. Specific PC programs were developed to identify vegetation percent cover^[3,6]. On the other hand, Purcell^[4] and Richardson, et al.^[5] used commercially available software to measure vegetation coverage and demonstrated that the results were accurate. Commercially available image editing or processing software packages are mainly based on two principles to distinguish different colored objects. One

is to distinguish different colored objects by different object color intensity. Among various image editing or processing software packages based on the above principle, Photoshop© is one of the most robust packages (Photoshop© 8.0 manual). The other principle to distinguish different objects is based on the values of R-B, R-G, or B-G. R, G, and B are the red, green, and blue color intensity respectively. Among various image editing or processing software tools based on this principle, the image analysis tool in Arcview© is one of the most robust tools.

In this study, we hypothesized that image analysis could be effectively used to measure the purity of desired-crop in the output product from crop cleaners, and that the data collection process would be more reproducible and less labor and time consuming than the traditional technique. Photoshop© and Arcview© software packages were used and compared for the analysis for fresh and dry harvest pictures for one chile cleaner.

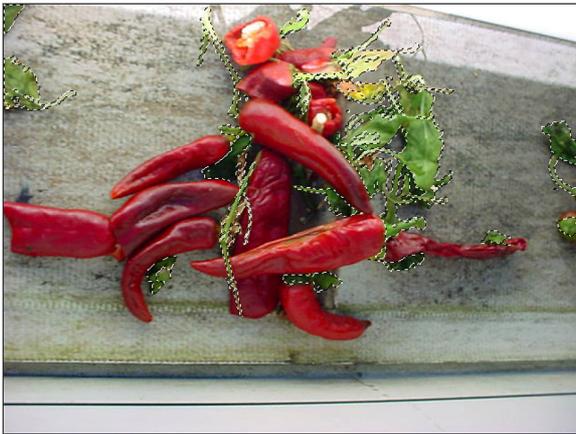
2 Materials and methods

2.1 Taking pictures

In fall (October) and winter (December) of 2003 and 2004, the chile cleaner designed by New Mexico State University was run in various chile fields in New Mexico. With the machine running and output steady after each adjustment, pictures of chile and trash (leaf and stem) on the output belt were taken by Sony digital camera (3 megapixel). In fall, the chile and trash were fresh. The chile was red and trash was green (Figure 1a). In winter, chile and trash were dry, most the chile was red and trash was yellow-white (Figure 2a).



a. Original



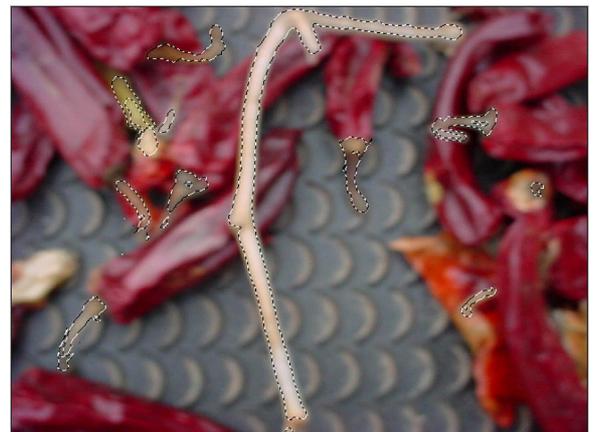
b. Leaf area chosen by Photoshop© (outlined)



a. Original



c. Leaf area chosen by Arcview©



b. Leaf area chosen by Photoshop© (outlined)



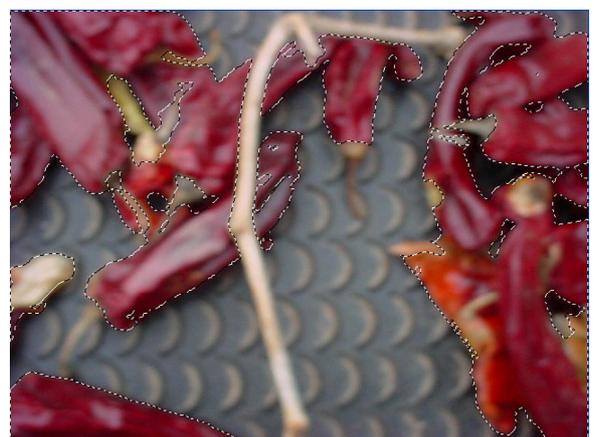
d. Chile area chosen by Photoshop© (outlined)



c. Leaf area chosen by Arcview©

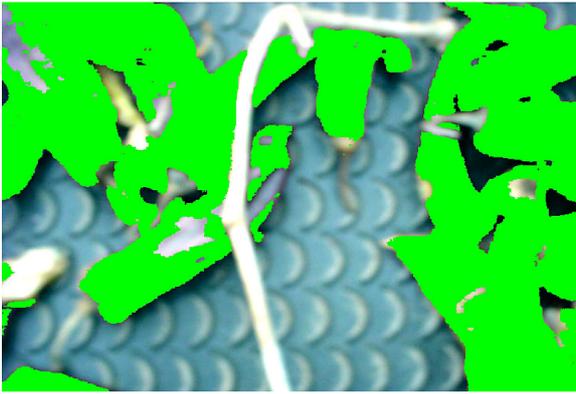


e. Chile area chosen by Arcview©



d. Chile area chosen by Photoshop© (outlined)

Figure 1 Processing of fresh harvest images



e. Chile area chosen by Arcview©

Figure 2 Processing of dry harvest images

2.2 Image analysis

2.2.1 Photoshop© 8.0

2.2.1.1 Tools introduction

When using Photoshop© 8.0 to do the image analysis, the major functions used are ‘Magic Wand Tool’, ‘Similar’ in ‘Select’ menu, and the ‘Histogram palette’. The ‘Magic Wand tool’  lets you select a consistently colored area (for example, a red flower) without having to trace its outline. You specify the color range, or tolerance, for the Magic Wand tool's selection (Photoshop© 8.0 manual). There is an ‘Options palette’ that allows adjustments to the Magic Wand settings. For example, the default tolerance value is set at 32, meaning that 32 similar lighter tones and 32 similar darker tones will be selected using the Magic Wand. There are several options for the tool, including ‘add a new selection’ , ‘add to an existing selection’ , and ‘subtract from a selection’ .

‘Similar’ in ‘Select’ menu expands a selection to include areas with similar color, including pixels, throughout the image that fall within the tolerance range. ‘Histogram palette’ can show the pixel numbers of any chosen areas in units of pixel. The picture resolution must be set to low enough (around or lower than 640 pixel×480 pixel, i.e., 2 mm×2 mm of chile or trash area is represented by one pixel on the image) for the ‘Histogram palette’ showing the accurate pixel numbers. Otherwise, the ‘Histogram palette’ only does subsampling and shows inaccurate (smaller) pixel numbers. The resolution is set in “Image Size” in “Image” menu.

2.2.1.2 Image processing

To process each picture, the ‘Magic Wand Tool’ (using the option of ‘add a new selection’) was used to choose the area interested (chile or trash). Then, ‘Similar’ tool in the ‘Select’ menu was chosen to mark similar color areas in the whole image. If the chosen areas did not include the most similar area, the process was repeated until it chose the most areas. After this, ‘add to an existing selection’ or ‘subtract from an existing selection’ in ‘Magic Wand Tool’ was used to add missed areas or subtract the wrongly chosen areas. The tolerance in the application was set to 30.

After all similar areas were chosen, the ‘Histogram palette’ was used to obtain the pixel numbers of the areas. After the trash and pepper pixels were obtained, the chile purity was calculated as: $\text{Pepper area} / (\text{Pepper area} + \text{Leaf area})$.

2.2.2 Arcview© 3.2 a

2.2.2.1 Tools introduction

When using ‘Arcview© 3.2 a’ to do the image analysis, the ‘Image Difference’ in ‘Image Analysis’ menu is used to distinguish the trash and pepper areas. Then, the picture is pasted into Photoshop©, where ‘Histogram palette’ is used to count the area pixels. A single image is divided to three layers in Arcview©: red, blue, and green component intensities for each pixel (intensity from 0 to 255). In the ‘Image Difference’ dialog, you can choose ‘Before Layer’ (R, G, or B) and ‘After Layer’ (R, G, or B). Then the options of ‘increases more than’ (‘After Layer’-‘Before Layer’) and ‘decreases more than’ (‘Before Layer’-‘After Layer’) can be set.

2.2.2.2 Image processing

Because ‘Image Difference’ in Arcview© distinguishes different color objects by the difference of color component intensities, i.e. R, G, and B, first we obtained the component intensities for pepper, trash (leaf and stem), and belt by randomly sampling five points for each object in each picture. This was done by putting the mouse on the object of interest; the color intensities can be automatically shown in Arcview©. According to each point R, G, and B values, the difference values of R-B, R-G, and B-G were calculated. Then in each

picture, for each object (pepper, trash, and belt), the means for R-B, R-G, and B-G were calculated, respectively. A one-way ANOVA was conducted to test if the means were significantly different between the three objects for each category of R-B, R-G, or B-G (Minitab© 2000). If the means are significantly different in one category, then the category may be used to set in Arcview© to discriminate the different object. For example, if the test shows that R-G means (58, -36.4, and 4.2) of the three objects (pepper, trash, and belt) are significantly different in one picture, then to distinguish pepper and trash, R-G category can be used. In Arcview©, 'Layer 2' (Green) can be set to 'Before Layer' and 'Layer 1' (Red) to 'After Layer'. The 'increase more than' may be set to 'value' of 58 or lower, and the 'decrease more than' may be set to 'value' of 36.4 or lower to segregate pepper and trash.

After the areas were chosen, the picture was pasted in Photoshop©, and the pixel counts were obtained using 'Histogram palette' in Photoshop©. After obtaining the pixel numbers of pepper and trash, the chile purity can be calculated as: $\text{Pepper area} / (\text{Pepper area} + \text{Leaf area})$.

2.3 Chile purity comparison with true values based on image methods

To compare which method is better, Photoshop© or Arcview©, five pictures each of fresh and dry harvest were chosen and processed by Photoshop© and Arcview©, respectively. To compare the purity with the true values, the picture was printed on paper. The pepper and trash were respectively cut out using scissors. Then the cut pepper and trash areas were measured with a leaf area meter (LI-3000 connected to LI 3050A, LI-COR Inc.). The chile purity was calculated for each picture.

The error ratio of chile purity measured by Photoshop© and Arcview© was calculated as the following.

$$\text{ErrorRatio} = \left| \frac{C_m - C_t}{C_t} \right|$$

where, C_m is the purity measured by Photoshop© or Arcview©; C_t is the true purity measured by leaf area meter. The average and standard deviation of the error ratios were calculated and compared for fresh and dry harvest pictures for Photoshop© and Arcview©,

respectively.

2.4 Time and cost comparison of image and weight-based methods

The time consumption and costs for image-based methods and weight-based methods were compared. The estimated average time consumed for each sample was compared.

The costs were estimated for equipment and labor costs based on 1 000 chile product samples (about the sample quantity in one field condition and complete adjustments). The technician operating image analysis software was assumed having a salary rate of 12 dollars/h. The technician for weight-based method was assumed having a salary rate of 10 dollars/h.

2.5 Correlation of purities of image and weight-based methods

In this study, we used image analysis to measure pepper purity for the output at different stages from the chile cleaner and assumed that the percent cover indirectly reflects the weight-based purity. To prove the assumption, 12 random samples of chile and trash mixtures were taken. The image-based purity was obtained by using Photoshop © and the dry weight-based purity was also obtained for each sample. Then correlation analysis was conducted to test if there exists significant correlation between the two purities.

3 Results

3.1 Photoshop©

Photoshop© can pick up pepper and trash effectively for fresh and dry harvest pictures (Figures 1b, 1d, and Figures 2b, 2d). In the pictures, the dash lines circle the selected areas.

3.2 Arcview©

3.2.1 Fresh harvest pictures

To distinguish the objects of fresh trash, pepper, and belt, the R-G or B-G category can be used because there was significant difference between the three objects in R-B or B-G. For example, in Figure 1, fresh pepper, trash, and belt had mean of 58, -36.4, and 4.2 respectively for R-G, and 11, -73.2, and -13.6 for B-G (Tables 1, 2, and 3). The means are significantly different for R-G ($F=24.74$, $P<0.001$) and B-G ($F=78.43$, $P<0.001$). The

means for R-B are not significantly different ($F=2.32$, $P>0.1$).

Table 1 Fresh pepper color component intensities and intensity differences

Color Sample	Red	Green	Blue	R-G	B-G	R-B
1	150	75	89	75	14	61
2	144	46	62	98	16	82
3	133	60	73	73	13	60
4	234	203	202	31	-1	32
5	122	109	122	13	13	0
Mean	156.6	98.6	109.6	58	11	47
Standard Deviation	44.6	62.9	56.4	34.9	6.8	31.7

Table 2 Fresh trash color component intensities and intensity differences

Color Sample	Red	Green	Blue	R-G	B-G	R-B
1	96	140	74	-44	-66	22
2	125	167	76	-42	-91	49
3	113	133	61	-20	-72	52
4	130	169	85	-39	-84	45
5	62	99	46	-37	-53	16
Mean	105.2	141.6	68.4	-36.4	-73.2	36.8
Standard Deviation	27.5	28.7	15.2	9.6	15.0	16.6

Table 3 Belt color component intensities and intensity differences for the fresh harvest

Color Sample	Red	Green	Blue	R-G	B-G	R-B
1	170	167	151	3	-16	19
2	177	163	143	14	-20	34
3	223	217	220	6	3	3
4	160	166	149	-6	-17	11
5	148	144	126	4	-18	22
Mean	175.6	171.4	157.8	4.2	-13.6	17.8
Standard Deviation	28.7	27.2	36.1	7.2	9.4	11.7

To distinguish green trash from the others, B-G values were used, and obtained better results than using R-G values. 'Layer 2' (Green) was set to 'Before Layer', and 'Layer 3' (Blue) was set to 'After Layer'. The 'decrease more than' value was set to 30, and the 'increase more than' value was set to 255 to choose trash only. The value 30 made the best trash discrimination. The 'increase more than' value 255 prevented choosing other objects because there was no other object that had the difference of 255 between R-B. (Figure 1c).

To distinguish pepper from the others, R-G values were used and obtained better results than using B-G values. 'Layer 2' (Green) was set to 'Before Layer' and

'Layer 1' (Red) was set to 'After Layer'. The 'increase more than' value was set to 20 and the 'decrease more than' value was set to 255 to choose pepper only. (Figure 1e).

3.2.2 Dry harvest pictures

To distinguish the objects of dry trash, pepper, and belt, the R-G, B-G, or R-G category could be used because there was significant difference between the three objects in each category. For example, in Figure 2, the mean of R-G for dry chile, trash and belt was 86, 31.6, and -7.6 respectively, for B-G, 19.4, -17, and 7, and for R-B, 66.6, 48.6, and -14.6 ((Tables 4, 5, and 6). The difference of the means for the three objects are significant for each category (R-G, $F=41.37$, $P<0.001$; B-G, $F=24.66$, $P<0.001$; R-B, $F=24.99$, $P<0.001$) (Tables 4, 5, and 6).

Table 4 Dry pepper color component intensities and intensity differences

Color Sample	Red	Green	Blue	R-G	B-G	R-B
1	165	83	104	82	21	61
2	153	77	94	76	17	59
3	123	2	26	121	24	97
4	114	13	30	101	17	84
5	146	96	114	50	18	32
Mean	140.2	54.2	73.6	86.0	19.4	66.6
Standard Deviation	21.2	43.4	42.2	26.7	3.0	25.1

Table 5 Dry trash color component intensities and intensity differences

Color Sample	Red	Green	Blue	R-G	B-G	R-B
1	237	207	198	30	-9	39
2	236	213	216	23	3	20
3	166	139	119	27	-20	47
4	160	116	86	44	-30	74
5	170	136	107	34	-29	63
Mean	193.8	162.2	145.2	31.6	-17.0	48.6
Standard Deviation	39.1	44.6	58.0	8.0	14.0	21.0

Table 6 Belt color component intensities and intensity differences for the dry harvest

Color Sample	Red	Green	Blue	R-G	B-G	R-B
1	116	123	132	-7	9	-16
2	112	122	128	-10	6	-16
3	104	106	114	-2	8	-10
4	98	103	108	-5	5	-10
5	86	100	107	-14	7	-21
Mean	103.2	110.8	117.8	-7.6	7.0	-14.6
Standard Deviation	11.9	10.9	11.5	4.6	1.6	4.7

To discriminate trash, B-G values were used, and the 'layer 2' (Green) was set to 'before layer' and 'layer 3' (Blue) 'after layer'. The value 10 was assigned to 'decrease more than' and 255 to 'increase more than'. Figure 2c shows the sample result..

To discriminate pepper, R-G values were used and the 'layer 2' (Green) was set to 'before layer' and 'layer 1' (Red) 'after layer'. The value 10 was assigned to 'increase more than' and 255 to 'decrease more than'. Figure 2e shows the sample result.

3.3 Comparison with true values

Photoshop© and Arcview© had accurate measurements for both dry and fresh harvest pictures (Tables 7 and 8). The mean error ratio was below 0.04 for Photoshop© and 0.12 for Arcview© for both of fresh and dry pictures.

Table 7 Chile purity measured by Photoshop© and Arcview© compared with the true value for fresh harvest pictures

Sample	Chile purity			Error ratio	
	True	Photoshop©	Arcview©	Photoshop©	Arcview©
1	0.691	0.693	0.609	0.002	0.082
2	0.576	0.586	0.569	0.009	0.007
3	0.675	0.644	0.625	0.032	0.051
4	0.756	0.737	0.688	0.019	0.068
5	0.867	0.886	0.669	0.019	0.198
Average				0.016	0.081
Standard deviation				0.011	0.071

Table 8 Chile purity measured by Photoshop© and Arcview© compared with the true value for dry harvest pictures

Sample	Chile purity			Error ratio	
	True	Photoshop©	Arcview©	Photoshop©	Arcview©
1	0.867	0.886	0.669	0.019	0.198
2	0.858	0.789	0.739	0.069	0.119
3	0.773	0.772	0.717	0.001	0.055
4	0.722	0.775	0.606	0.052	0.117
5	0.826	0.857	0.744	0.031	0.082
Average				0.035	0.114
Standard deviation				0.027	0.054

Generally, Photoshop© had better accuracy than Arcview©. For fresh harvest pictures, Photoshop© had a mean error ratio of 0.016 and standard deviation of 0.011 compared with Arcview© at 0.081 and 0.07. Arcview© may choose the non-trash area as the trash area

(belt in Figure 1c) and choose the non-pepper area as pepper (yellow leaf in Figure 1e). Photoshop© did not have these errors because the options of 'add to an existing selection' and 'subtract from a selection' can manually select (deselect) the missed area (wrongly chosen area) effectively.

For dry harvest pictures, Photoshop© resulted in a mean error ratio of 0.035 and standard deviation of 0.027 compared with Arcview© 0.114 and 0.054. For the dry harvest pictures, Arcview© cannot distinguish the dry trash well. It may not completely distinguish the trash and may add in some light color pepper (Figure 2c). Also, in choosing pepper area, Arcview© may not distinguish the light color pepper and may lose the pepper area (Figure 2e). Photoshop© did not produce these errors because the options of 'add to an existing selection' and 'subtract from a selection' can manually select (deselect) the missed area (wrongly chosen area) effectively.

3.4 Time and cost comparison of image and weight-based methods

Image-based methods use much less time to obtain the chile purity than the weight-based methods (Table 9). Using Photoshop© only spends about 45 s to process each sample for the whole procedure (The operation of downloading pictures to a PC was assumed a batch operation which downloads a batch of pictures each time). Dry-weight-based method spends about 470 s (even we do not count the transportation and drying time).

Table 9 Comparison of time used for each sample processing for image and weight-based methods

	Image analysis methods		Weight-based methods		
	Photoshop©	Arcview©	Dry weight based	Wet weight based	
				Time spent for each sample/s	
Taking sample	5	5	Taking sample	90	90
Downloading and storing	5	5	Bagging	90	
Separating	30	20 ^a	Storing	20	
Obtaining area and purity	5	60	Separating	180	180
			Drying	24 h	
			Weighing	90	90
Average	45	90		470 ^b	360

Note: ^a: the determination for R-G, R-B, and B-G for a batch of samples at the first time may need 30 min. ^b: drying and transportation time is not counted.

Weight-based methods cost more mainly from the labor costs because the methods need more labors and much more time (Tables 10 and 9). The total wet weight-based method costs about \$2 700 for about 1 000 samples and the dry-weight based costs about \$5 700 (transportation fee was not counted). But the image-based methods cost only about \$500-550.

3.5 Correlation of purities measured by image and dry weight- based methods

The correlation of the purities measured by image and dry weight- based methods is significant (correlation= 0.96, $p < 0.001$). Then, the purity obtained from image methods indirectly reflects the purity obtained from weight-based methods.

Table 10 Comparison of costs for measuring purities of 1 000 samples by image and weight-based methods

Image analysis methods					Weight-based methods				
Procedure	Photoshop©		Arcview©		Procedure	Dry weight-based		Wet weight-based	
	Equipment and labor	Price/\$	equipment	Price/\$		Equipment and labor	Price/\$	equipment	Price/\$
Taking sample	camera	100	camera	100	Taking sample				
Separating					Separating	Refrigerator	2 000		
Obtaining area and percent cover	Software	300 ^a	Software	250 ^a	Bagging	Bags	1		
	Labor	150	Labor	150	Drying	Oven	1 000		
Total		550		500	Weighing	Electronic scale	200	Electronic scale	200
						Labor	3 000	Labor	2 500
							5 700		2 700

Note: ^a: the price is for educational institutes. Some image analysis software packages are free such as Image J. Assumed a pc is available in a lab which does not cost money for the image analysis.

4 Conclusions

Using image analysis methods, one can quickly, accurately and conveniently obtain the crop purity of products outputted from cleaners. The purity indirectly reflects the weight-based purity. Photoshop© produced better accuracy than Arcview©. For fresh harvest pictures (chile and trash mixture), Photoshop© resulted in a mean error ratio of 0.016 and standard deviation of 0.011 compared with Arcview© 0.081 and 0.07. For dry harvest pictures, the mean error ratio was within 0.035; standard deviation was within 0.027 for Photoshop© compared to 0.114 and 0.054 for Arcview©.

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