Determination of the minimum dry matter index for the optimum harvest of 'Hass' avocado fruits in Colombia

Determinación del índice mínimo de materia seca para la óptima cosecha del aguacate 'Hass' en Colombia

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ABSTRACT

Colombia has become an important producer of 'Hass' avocado in the last three years; however, a minimum dry matter content has not been established as a maturity index for harvest. The aim of this study was to determine the correlation between oil percentage and dry matter content in order to establish a minimum harvest index for 'Hass' avocado fruits grown in Colombia. Samples were collected for maturity determinations over three years of 'Hass' avocado fruit cultivation from fifteen different orchards in the department of Antioquia in order to determine the dry matter and oil percentage of fruits throughout the season. A simple linear relationship between oil content and dry matter was thus established. The equations for all of the studied orchards presented a good correlation coefficient, ranging between 0.70 on the Cartucho orchard in the municipality of Retiro and 0.99 on the Gacamayas and Paraiso orchards in the municipality of Entrerrios and Retiro. Using the minimal oil standard of 11.2% as a reference, the orchards that were found to have a high dry matter percentage at harvest were Cartucho in Retiro (26%), followed by Piedras Blancas and Santa Cruz in the municipality of Venecia (25%); while the 'Hass' avocado fruit from the Cebadero orchard in Retiro, Coconi in the municipality of La Ceja and Guacamayas in Entrerrios reached this oil standard at 22% dry matter, which could be a commercial advantage. Based on these oil content results, a minimal dry matter index of 23.5% was proposed as a harvest maturity indicator for 'Hass' avocado grown in Colombia. This harvesting index will need to be refined over time and with the addition of samples from more regions and climatic data profiles.

Key words: *Persea americana* Mill., oil percentage, maturity index, quality, region, Antioquia.

RESUMEN

Colombia se ha convertido en un importante productor de aguacate 'Hass' en los últimos tres años. Sin embargo, no se ha establecido aún un contenido mínimo de materia seca para cosecha. El objetivo de este estudio fue determinar la correlación entre el porcentaje de aceite y material seca para definir un índice mínimo de cosecha para el aguacate 'Hass' cultivado en Colombia. Se recogieron muestras de frutos de aguacate 'Hass' durante tres años en quince fincas diferentes en el departamento de Antioquia para determinar el porcentaje de materia seca y aceite de la fruta durante la temporada. Se estableció una relación lineal simples entre el contenido de aceite y materia seca para el departamento de Antioquia. Las ecuaciones para todas las fincas estudiadas presentaron un buen coeficiente de correlación, que osciló entre 0,70 en la finca Cartucho del municipio de Retiro y 0,99 en las fincas Gacamayas y Paraíso de los municipios de Entrerrios y Retiro, respectivamente. Utilizando como referencia el 11,2% como el estándar mínimo de aceite para cosecha, las fincas que registraron un porcentaje de materia seca más alto para cosecha fueron Cartucho del Retiro (26%), seguida de Piedras Blancas y Santa Cruz para el municipio de Venecia (25%), mientras que las fincas Cebadero del Retiro, Coconi del municipio de La Ceja y Guacamayas de Entrerrios, alcanzaron este mismo porcentaje con 22% de materia seca, lo que puede ser considerado una ventaja comercial. A partir de estos resultados de contenido de aceite un índice mínimo de materia seca de 23,5% fue propuesto como indicador de la madurez para cosecha de aguacate 'Hass' cultivado en Colombia. Este índice de cosecha deberá ser refinado con el tiempo y con la adición de muestras de más regiones y datos climáticos.

Palabras clave: *Persea americana* Mill., porcentaje de aceite, índice de madurez, calidad, región, Antioquia.

Introduction

Colombia exported several containers of 'Hass' avocado (*Persea americana* Mill.) to Europe in the last few years. The country, during that time, had about 6,300 ha of 'Hass' avocado production spread over 9 provinces. The national production amounted to 27,532 t, with an average yield of 4.03 t ha^{-1} and 19 kg/tree. 'Hass' avocado production made up 25.4% of the cultivar spread in the nation (Mejía, 2012).

Avocado is a climacteric fruit that does not ripen on the tree, so it must be harvested during the suitable physiological

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maturity stage to achieve the edible characteristics of taste and firmness (Gil, 2000; Gamble *et al.*, 2010). It is very hard to visually determine the appropriate maturity stage in the 'Hass' avocado for harvesting because the fruit does not exhibit any notable external change in appearance (Kassim *et al.*, 2013). Thus, it is not uncommon to find 'Hass' avocado fruits in the market at the expected maturity stage with an uncharacteristic color and a shriveled peel, especially early in the season (Osuna-García *et al.*, 2010; Pedreschi *et al.*, 2014).

During the maturation process, there is an increase in the oil content of the fruit, a moisture reduction and an increase in palatability (Ozdemir and Topuz, 2004; Osuna-García *et al.*, 2010). A popular method for determining oil content in the avocado is the Soxhlet method (Lee, 1981). However, it is slow, expensive and difficult to perform; thus, people prefer to use the indirect method of using the percentage of dry matter of fruit pulp as an indication of maturity. This method is based on the high correlation between a decrease in fruit moisture content and an increase in dry matter or an increase in the oil content of fruit (Lee *et al.*, 1983; Woolf *et al.*, 2004).

The use of the percentage of dry matter as a maturity indicator for avocado is widely accepted and minimum values have been established as a legal standard for each cultivar in most countries. The minimum requirement of dry matter varies from 19 to 25%, depending on the cultivar (19.0% for Fuerte, 20.8% for Hass and 24.2% for Gwen) and the country (21% for Australia, 21.6-22.8% for USA and 23.0% for Mexico, South America and South Africa for 'Hass' avocado) (Hofman *et al.*, 2002; Orhevba and Jinadu, 2011; Kassim *et al.*, 2013).

Fruits harvested with dry matter levels below the recommended minimum will ripen irregularly and will not fully develop their quality attributes. Similarly, fruits harvested with a high dry matter undergo rapid ripening and have a reduced shelf life (Wu *et al.*, 2011). Studies by Whiley *et al.* (1996) indicated that early harvesting of late-maturing 'Hass' at 25 to 30% dry matter resulted in high productivity; whereas, harvesting at 35% dry matter reduced yields, also leading to alternate bearing.

The oil content in avocados depends on several factors, such as the cultivar (Chen *et al.*, 2009; Dodd *et al.*, 2010; Orhevba and Jinadu, 2011), agro-ecological conditions of growth (Landahl *et al.*, 2009; Kassim *et al.*, 2013; Wedding *et al.*, 2013; Donetti and Terry, 2014) and the fruit development stage (Ozdemir and Topuz, 2004; Osuna-García *et al.*, 2010; Villa-Rodríguez *et al.*, 2011).

Since 1925, a minimum standard of 8% oil content in the pulp of avocado fruit was used in the California Avocado Industry in the United States, but since the eighties they began using minimum oil content percentages for each cultivar (*e.g.* 10.0% for Fuerte and 11.2% for Hass) (Anon, 1925; Lee *et al.* 1983; Ozdemir and Topuz, 2004; Dodd *et al.*, 2010).

Lee *et al.* (1983) examined the relationship between dry weight, oil and sensory perception. They concluded that regional harvest dates were not appropriate. There was also discussion as to whether the same dry matter level means the same "taste acceptability" in different countries or, even possibly, in different regions within a country.

In Colombia, genetic and agro-ecological variability are very high, hindering homogeneous fruit production and management and the prediction of the correct harvest date. Bearing these conditions in mind, it is rather challenging to make Colombian 'Hass' fruits competitive and to create synergy with regional countries such as Mexico and Chile.

The correlation between oil and dry matter percentage for 'Hass' avocado fruit has not been established yet in Colombia. However, in relation to the growing area, the determination of the minimum percentages of oil and/or dry matter should help determine when to harvest. Limits on harvest maturity should be set in order to achieve standardization of fruit quality for an export-based industry.

The aim of this study was to determine the correlation between oil percentage and dry matter content to establish a minimum harvest index for 'Hass' avocado fruits grown in Colombia. This will be a useful tool for farmers targeting the export market and aiming to deliver fruits at the optimum commercial maturity and quality, using adequate transport, storage and shelf life.

Materials and methods

Plant material

To determine the relationship between the dry matter and oil percentage of 'Hass' avocado in different municipalities of the department of Antioquia, Colombia, we selected different orchards at different altitudes above sea level (Tab. 1). In each orchard, one tree of the same age and with a normal level of production were selected in a homogeneous area of the plot. Eight fruits of different maturity stages, determined by the size and bright of the peel, were harvested to build a maturation curve. At least two harvests were done for each orchard and the evaluation was carried out between 2011 and 2013 (Tab. 1).

After harvest, the fruits were immediately brought to the Postharvest Laboratory of the La Selva Research Center of Corpoica (*Corporacion Colombiana de Investigacion Agropecuaria*) in Antioquia to determine dry matter. The samples of dry avocado pulp were stored at ambient room conditions inside a desiccator with silica gel until the oil percentage was determined.

Dry matter

The dry matter (DM) was determined according the Lee method (Lee, 1981). The samples were dried at 60ºC until they reached a constant weight. The final and initial weight differences were used to calculate the dry matter percentage.

TABLE 1. Orchards selected for the study of maturity index of 'Hass' avocado in the department of Antioquia, Colombia.

Municipalities	Orchard	Altitude (m a.s.l.)	Latitude (N)	Longitude (W)	Orchard age (years)	Orchard area (ha)	Harvest date
Támesis	La Maria	1,340	05°41'21.6"	75°42'15.7"	5 to 6	-	23/08/2011 29/06/2012
Venecia	Piedras Blancas	1,510	05°55'58.0''	75°45'33.4''	5	16	16/08/2011 22/06/2011 03/09/2012
Venecia	Santa Cruz	1,770	05°55'50.3''	75°46'53.1''	4	20	05/10/2011 17/08/2011 14/06/2012
Jericó	El Encanto	1,900	05°47'48.7"	75°45'45"	3	6	06/10/2011 23/08/2012
Rionegro	Yeguas	2,183	06°08'28.1''	75°27'28.8''	4 a 8	8.17	19/12/2012 27/12/2012 30/01/2013
El Retiro	Cartucho	2,229	06°04'58''	75°27'22.8''	4 a 7	4	17/12/2012 26/12/2012 30/01/2013
El Retiro	Guarango	2,244	06°02'57.2''	75°29'48''	6	9.8	10/12/2012 17/12/2012 14/02/2013
Rionegro	La Escondida	2,248	06°05'53''	75°44'20"	5	14	29/09/2011 21/06/2012
El Retiro	Casaloma	2,267	06°01'42''	75°30'16.1''	4	0.2	11/12/2012 28/12/2012 30/01/2013
El Retiro	Isabela	2,303	06°00'57.4''	75°29'28.7''	7	1.43	07/12/2012 27/12/2012 14/02/2013
El Retiro	Cebadero	2,364	06°01'46.7''	75°27'51.1''	3 a 5	40	07/12/2012 18/12/2012 14/02/2013
La Ceja	Coconi	2,381	06°00'41.9''	75°26'10.2''	6	0.42	14/12/2012 26/12/2012 30/01/2013
La Ceja	Entreaguas	2,383	05°57'18.3''	75°25'10.3''	5	9.41	13/12/2012 26/12/2012 30/01/2013
El Retiro	Paraiso	2,383	06°05'10''	75°27'23''	5	-	17/12/2012 26/12/2012 30/01/2013
Entrerrios	Guacamayas	2,420	06°33'39.4''	75°32'28.6''	5	5.39	28/07/2011 07/06/2012

Oil percentage

The oil percentage of the dry samples was determined by the Horwitz (1980) and Lee methods (Lee, 1981). A 10 g sample of dry avocado pulp was used to extract the lipids by Soxhlet for 6-8 h using petroleum ether as a solvent. The oil percentage of the avocado pulp was calculated with the following equation and expressed as % (w/w).

$$\text{Oil content (\% w/w)} = \frac{\text{dry matter (\%) x oil weight (g)}}{\text{dry pulp weight (g)}} \quad (1)$$

The dry matter and oil content values were further used to estimate the correlation coefficient and a linear regression model for each orchard.

Statistical analysis

The results were analyzed by the Statgraphics® Centurion XVI v. 15.2 (StatPoint®, Herndon, VA). A simple linear regression model was applied for determining the relationship between the oil and dry matter percentages. Then an analysis of variance (ANOVA) test was performed to determine the representativeness of the model with a LSD test at 95% level of confidence.

Results and discussion

The results showed a positive correlation between the dry matter and oil percentages of the fruit pulp for all the studied orchards during the three years of evaluation (Figs. 1 and 2). A close relationship between oil content and dry matter content was thus confirmed (Tab. 2). An increased lipid concentration in fruit as a result of a reduced percentage of water has been reported by many authors (Chen *et al.*, 2009; Gamble *et al.* 2010; Villa-Rodríguez *et al.*, 2011).

Fruit samples from all of the analyzed orchards presented a good correlation coefficient, with the lowest at 0.84 on the Cartucho orchard in Retiro and the highest at 0.99 on the Gacamayas and Paraiso orchards in Entrerrios and Retiro. These correlation values are similar to those reported by other authors for avocado fruits (Olaeta *et al.*, 1986; Chen *et al.*, 2009).

The degree of correlation obtained between the oil content and dry matter of avocado fruit pulp was important because the direct estimation of oil percentage of avocado fruits is difficult, slow and expensive. With the current results, we can indirectly and reliably estimate the oil content of fruits using dry matter values in a linear regression equation, which is practical and easy (Lee, 1981). The regression equation for each orchard is presented in Tab. 2. With this equation, a farmer can estimate the oil content of a fruit sample based on the determined dry matter percentage.

The dry matter percentage is often used as a maturity index in most avocado producing areas in the world. In the valleys of the central coast of Peru, 'Hass' avocado is usually harvested with a minimum oil content of 8-9% and with a 20-21% dry matter content (Franciosi, 2003). The 'Hass' Avocado Committee of Chile authorizes the commercial harvest of 'Hass' fruit with a minimal dry matter content of 23% (Waissbluth and Valenzuela, 2007).

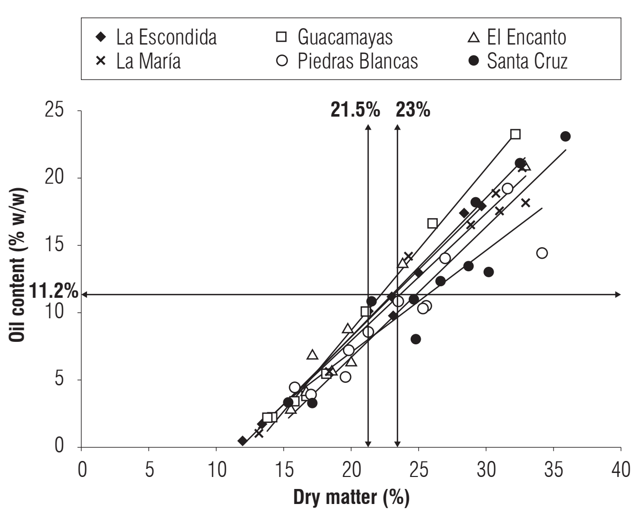

FIGURE 1. Correlation between oil content and dry matter for 'Hass' avocado grown in different orchards of department of Antioquia, Colombia between 2011 and 2012.

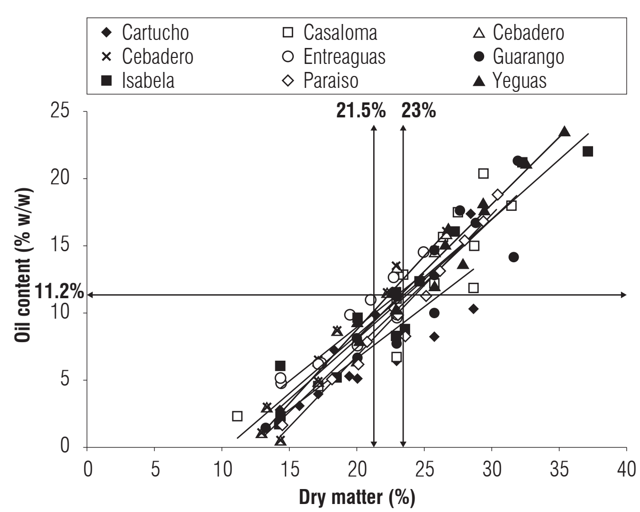

FIGURE 2. Correlation between oil content and dry matter for 'Hass' avocado grown in different orchards of the department of Antioquia, Colombia, between 2012 and 2013.

TABLE 2. Regression equations of oil percentage and dry matter for 'Hass' avocado in different municipalities of department of Antioquia, Colombia.

Municipalities	Orchard	Altitude (m a.s.l.)	Equation	Correlation coefficient	*P*<0.05*	Dry matter (%) for 11.2% of oil
Támesis	La Maria	1,340	Oil (%) = -10.90 + 0.95*DM (%)	0.98	0.0000	23
Venecia	Piedras Blancas	1,510	Oil (%) = -8.02 + 0.76*DM (%)	0.92	0.0000	25
Venecia	Santa Cruz	1,770	Oil (%) = -12.66 + 0.97*DM (%)	0.94	0.0000	25
Jericó	El Encanto	1,900	Oil (%) = -12.19 + 1.03*DM (%)	0.97	0.0000	23
Rionegro	Yeguas	2,183	Oil (%) = -11.82 + 0.99*DM (%)	0.97	0.0000	23
El Retiro	Cartucho	2,229	Oil (%) = -8.63 + 0.76*DM (%)	0.84	0.0006	26
El Retiro	Guarango	2,244	Oil (%) = -14.23 + 1.08*DM (%)	0.95	0.0000	24
Rionegro	La Escondida	2,248	Oil (%) = -11.65 + 0.99*DM (%)	0.99	0.0000	23
El Retiro	Casaloma	2,267	Oil (%) = -8.89 + 0.86*DM (%)	0.89	0.0001	23
El Retiro	Isabela	2,303	Oil (%) = -9.76 + 0.89*DM (%)	0.96	0.0000	23
El Retiro	Cebadero	2,364	Oil (%) = -13.15 + 1.09*DM (%)	0.96	0.0000	22
La Ceja	Coconi	2,381	Oil (%) = -3.18 + 0.65*DM (%)	0.98	0.0000	22
La Ceja	Entreaguas	2,383	Oil (%) = -7.04 + 0.80*DM (%)	0.90	0.0000	23
El Retiro	Paraiso	2,383	Oil (%) = -14.03 + 1.06*DM (%)	0.99	0.0000	24
Entrerrios	Guacamayas	2,420	Oil (%) = -15.08 + 1.19*DM (%)	0.99	0.0000	22

* For a P-value of ANOVA inferior to 0.05, there was a statistical relationship between oil and dry matter (DM) with a confidence level of 95.0%.

Law number 422 of California, established in 1925, specified 8% as the minimal oil fruit content before harvesting could commence (Anon, 1925). Nevertheless, the oil content of fruit that was considered acceptable for consumption differed among cultivars and the 8% requirement was too low to serve as a good maturity standard for many cultivars according (Lee *et al.*, 1983; Chen *et al.*, 2009; Dodd *et al.*, 2010). In addition, while the date of acceptable taste of fruit grown at the same location was not significantly different from year to year, it varied significantly among and within the widespread avocado production areas.

Morton (1987), based on experiences in Mexico, stated that fruit reaches a good taste when the fruit has a minimum oil content of 8% and dry matter of 21%. Olaeta *et al.* (1986) defined the minimal oil content for 'Hass' avocado in Chile as 10%. After the eighties, California (USA) started using higher minimal oil percentages and discerning between cultivars; for example: 10.0% for Fuerte and 11.2% for Hass (Lee *et al.*, 1983).

It is also important to note that fruit quality starts to deteriorate when dry matter is too high. Picking overly-mature fruits results in poor flavor and increased fruit diseases and flesh disorders, as well as reduced yields of the next crop (Whiley *et al.*, 1996; Osuna-García *et al.*, 2010; Wu *et al.*, 2011). Fruit should not be left on trees beyond the normal picking period. For this reason, a maximum cut-off for harvesting 'Hass' avocado fruits should be defined. Thorp *et al.* (1997), studying the postharvest quality of New Zealand-grown 'Hass' avocado, observed that fruit harvested with a dry matter above 26% had severe rot.

Prior to the current research study, Colombian growers and fruit handlers had no standard index defined for the commercial harvest of 'Hass' avocado. In this study, we used the standards of other countries as a reference; for example, dry matter between 21.5 and 23% and an oil content of 11.2% to see when the different orchards reach the physiological mature stage for harvest (Figs. 1 and 2).

The standard oil percentage was considered to be a better harvest indicator for avocado because it relates well with fruit flavor. As can be seen in Fig. 1, none of the studied orchards with a dry matter of 21.5% reached an oil content of 11.2%, nor did the studied orchards in Fig. 2. From both figures, we can see that all of the studied orchards reached the same oil content, but with different accumulation rates (slope of the straight), reaching the physiological mature index at different times.

When we compared the different orchards for the physiological standard of oil content (11.2%), the percentage of dry matter ranged from 22 to 26% (Tab. 2). It is interesting to note that 'Hass' avocado fruit from the Cebadero orchard in Retiro, Coconi in La Ceja and Guacamayas in Entrerrios reached this oil standard earlier (for 22% dry matter) when compared to the other orchards, which could be a commercial advantage. The orchards with a high dry matter percentage for harvest in this study were Cartucho in Retiro (26%), followed by Piedras Blancas and Santa Cruz in Venecia (25%).

More evaluations over time and for more orchards are needed for a better understanding of the effect of altitude and climate on physiological maturity and variables such as PAR radiation, solar radiation and accumulated precipitation must be considered in the evaluation.

Different authors (Kaiser *et al.*, 1992; Kruger, 1999; Landahl *et al.*, 2009; Donetti and Terry, 2014) reported that the oil and moisture contents of 'Hass' and 'Fuerte' avocado, at the same date, vary year by year; probably because of the climatic conditions for a specific year and the rainfall and temperature variation of the seasons. They observed that the accumulation of dry matter percentage can be higher in seasons with higher rainfall and longer exposure to solar radiation. Woolf *et al.* (1999) confirmed that sun-exposed 'Hass' avocado fruits had higher contents of dry matter, potassium, calcium and magnesium. These fruits took longer to mature and the side exposed to the sunlight had higher firmness as compared to the unexposed side.

Waissbluth and Valenzuela (2007) inferred that, in Chile, fruit maturity is more related to altitude than to the north/south orientation. According to Ferreyra and Defilippi (2012), the orchards on the coast of Chile take 55 d longer to reach 23% dry matter than the ones in the central valley zone due to climatic conditions and also probably due to agronomic practices (nutrition, pruning, orchard age, orchard density, and others). The same authors established the maximum limit of dry matter for a good shelf life and fruit quality at 27.5% (> 27.5% high risk and < 27.5% low risk).

The linear model with all the data collected between 2011 and 2013 from different orchards of Antioquia is shown in Fig. 3. The model exhibited a statistical significance at 95% for the relationship between oil and dry matter and a good fit, explaining 93.4% of the oil content variability. The coefficient of 0.95 indicated a strong relationship between the two variables. The equation in Fig. 3 can be used by any grower in Antioquia, although the model needs to be refined with more data over time (harvest seasons and years) and with fruit from more orchards to be more accurate. However, according to this model, the oil content standard of 11.2% corresponded to a dry matter of 23.5%. This could be considered the minimal index at which one can harvest 'Hass' avocado in Antioquia and guarantee good taste and fruit quality, despite the variation that might exist between orchards as seen in Tab. 2.

It is also important to define a maximum harvest index of dry matter percentage related to shelf life and fruit quality during transport and storage. Colombia must define clear rules for establishing the adequate grade and harvest date

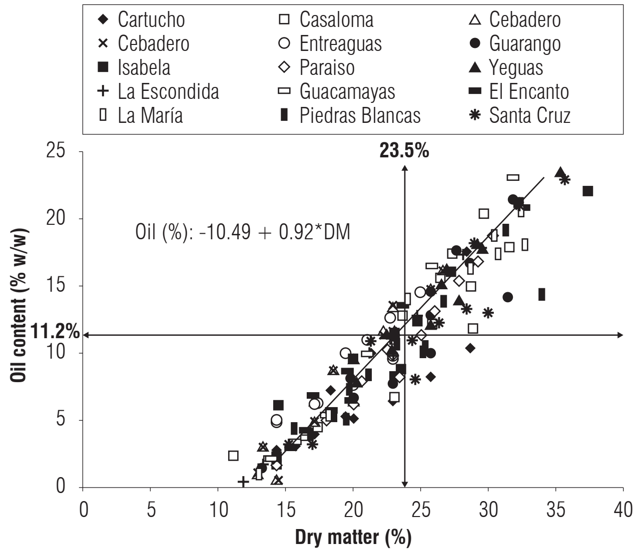

FIGURE 3. Linear model of relation between oil content and dry matter for 'Hass' avocado in department of Antioquia, Colombia.

according to the cultivar and producing region. Until now, there has been no scientific evidence and, consequently, harvesting has been done based on past (empirical) agricultural experience: namely fruit color and size. A protocol for sampling the orchards with the minimun dry matter index for 'Hass' avocado at harvest must now be defined by governmental entities.

In addition to the issues involved in simply measuring dry matter, an important area which requires greater understanding is the relationship between oil content (dry matter) and various flavor attributes of avocados and not just an "overall consumer acceptability". According to Obenland *et al.* (2012), neither dry matter nor oil percentage are adequate in of themselves to fully explain the differences in the eating quality of avocados so additional means of assessing eating quality would be desirable. The development of sensory descriptors and their relationship with aroma volatiles for 'Hass' avocado in Colombia could be useful for better linking maturity changes with flavor. This might help in examining regional effects in terms of oil content levels and flavor (Gamble *et al.*, 2010; Paull and Duarte, 2011; Yahia and Woolf, 2011). A correlation superior to 0.93% between fruit taste and oil percentage was observed by Olaeta *et al.* (1986) when studying different avocado cultivars (Fuerte, Bacon, Edranol, Hass, Butano and Negra de La Cruz).

Conclusions

The oil content of the fruits showed a positive highly significant correlation (superior to 0.80) with the percentage of dry matter for all of the studied orchards. An equation to estimate oil percentage in relation to dry matter percentage was defined with a good fit for each studied orchard. A simple linear model was defined for Antioquia to determine oil content in relation to dry matter percentage with a very high correlation coefficient. This is a very useful tool for 'Hass' avocado producers because the determination of oil content is very expensive. In this way, they can predict that the fruits will meet the required optimum postharvest quality. Using the minimal oil standard of 11.2% as a reference, the minimal dry matter index for harvesting 'Hass' avocado in Colombia was defined as 23.5%. Nevertheless, more evaluations over time (harvest seasons and years) and with more regions and climatic data are needed to develop a more accurate model. As Colombia is a country with a very high climate variability over short distances, a model of oil and dry matter percentage for each producing region should be developed. The minimal oil content needed to reach physiological maturity and a good flavor for 'Hass' avocado must also be defined for Colombian 'Hass' fruits grown in different regions.

Acknowledgments

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