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Non-Destructive leaf area estimation in fruits: update and state of the art

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RESUMEN

The aim of this study was to carry out a systematic review on non-destructive estimation of leaf area in fruit trees. Articles published (N= 66) in scientific journals during the last 20 years (2000-2020) were analyzed. A standard systematic review was conducted, adjusted to the guidelines of the PRISMA statement. The most outstanding results indicate that the models developed to estimate the leaf area in fruit trees have been carried out mainly in developing countries. In general, these are linear models, based on the measurement of the height and width of the leaf, using a portable meter to measure leaf area. Likewise, most of the estimation models have been validated in the same study, which gives them a strong agreement between predicted and measured data. It is expected that the review presented here will constitute a reference material for technicians, professionals and researchers interested in this topic.

Key words: systematic review, update, leaf area, indirect estimation, fruit crops.

ABSTRACT

Estimación no destructiva del área foliar en frutales: actualización y estado del arte.
El objetivo del presente trabajo fue realizar una revisión sistemática de la bibliografía sobre estimación no destructiva del área foliar en frutales. Se analizaron 66 artículos publicados en revistas científicas durante los últimos 20 años (2000-2020). Se realizó una revisión sistemática estándar, ajustada a las pautas de la declaración PRISMA. Los resultados más destacados indican que los modelos se han realizado principalmente en países en desarrollo. En general, se trata de modelos lineales, basados en la medición del alto y ancho de la hoja mediante algún medidor portátil del área foliar. Asimismo, la mayoría de los modelos incluidos en esta revisión han sido validados en el mismo estudio, lo que les confiere un fuerte acuerdo entre los datos medidos y los estimados. Se espera que la revisión que aquí se presenta constituya un material de consulta para técnicos, profesionales e investigadores interesados en esta temática.

Key words: revisión sistemática, actualización, área foliar, estimación indirecta, frutales.

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INTRODUCTION

The leaf is the exchange surface between the plant and the environment. It is the organ where the conversion of sunlight into biochemical energy occurs (Blanco and Folegatti, 2005; Pandey and Singh, 2011). The intensity of these exchanges, as well as the photosynthetic activity, have a direct relationship with the leaf area (Mokhtarpour *et al*., 2010). For this reason, among the variables that characterize the leaves, the leaf area and the parameters associated with it (leaf area index, net assimilation rate, specific leaf area, specific leaf weight) are the most representative, especially in relation to physiological and environmental factors (Sala *et al*., 2015).

Leaf area is a valuable index to identify and understand many agronomic and physiological processes, such as photosynthetic efficiency, evaporation, respiration, water balance, transpiration, energy balance, yield potential, response to irrigation and fertilizers (Blanco and Folegatti, 2005, Fotis *et al*., 2018). Although the precise estimation of the foliar area is very important in all crops, it is crucial in fruit trees (Santesteban *et al*., 2006) due to its impact on the size and filling potential of the fruit (Demirsoy, 2009, Keramatlou *et al*., 2015). In this sense, Grantz and Williams (1993) pointed out early that the distribution and density of the foliar area affects, although indirectly, the quality of the fruit and the incidence of diseases. This is so because the amount of solar radiation intercepted by the canopies influences the microclimate (light, temperature and humidity) within them (Jianga *et al*., 2017). Hence, the measurement of the leaf area is of particular importance both for the study of plant physiology, and for analyzing the vegetative and reproductive responses of plants to climatic conditions and to different agronomic and management practices.

In general terms, the leaf area can be estimated through direct or indirect methods (Weiss *et al*., 2004). Direct methods, although considered the most accurate, are destructive and require expensive instruments, which gives them limited applicability (Kumar *et al*., 2017). Through direct methods, the total area is usually obtained by measuring the area of all the excised leaves of the plant (Fallovo *et al*., 2008). By destroying the leaf, it is not possible to make successive measurements when it is necessary, for example, to verify the evolution of the plant during the growing season (Jonckheere *et al*., 2004).

Indirect methods allow in situ estimation of the leaf area, not require the leaves to be detached, reduce the variability associated with destructive sampling procedures and allow repeated measurements during the growth period of the plant. They are fast, non-destructive, simple, reliable, inexpensive and susceptible to automation (Keramatlou *et al*., 2015). In indirect methods, the leaf area is inferred directly from observations of some proxy variables, such as leaf length, leaf width or some combinations of these variables (Fascella *et al*., 2015). The measured variables constitute inputs for the development of mathematical models to predict the leaf area.

The non-destructive prediction of the leaf area using simple equations has become a common tool in agronomy. In general, leaf area estimation models consist of performing a regression analysis in which the leaf area acts as a dependent variable, and the length and width of the leaf as independent variables (Kumar, 2009). Simple mathematical models allow the measurement of the leaf area in the same plants during the growth period and help reduce variability in experiments (Khan *et al*., 2016). Different mathematical models can be elaborated for the indirect estimation of the leaf area for several cultivars, species and genotypes, or the same model can be applied for several cultivars and different species.

The review of the scientific literature shows an important number of predictive models of the foliar area for fruit crops. Such profusion requires some systematization for the purpose of offering practical and agile consultation tool. Therefore, the general objective of this study was to carry out a systematic review of the studies on the non-destructive estimation of the leaf area in fruit trees published during the first 20 years of this century (from January 2000 to January 2020).

MATERIALS AND METHOD

For the execution of this study, the guidelines of the standard systematic review were followed, as described in Preferred Reporting Items for Systematic Review and Meta-Analyzes (PRISMA) (Moher *et al*., 2009). Figure 1 shows the search and selection sequence of the analyzed articles.

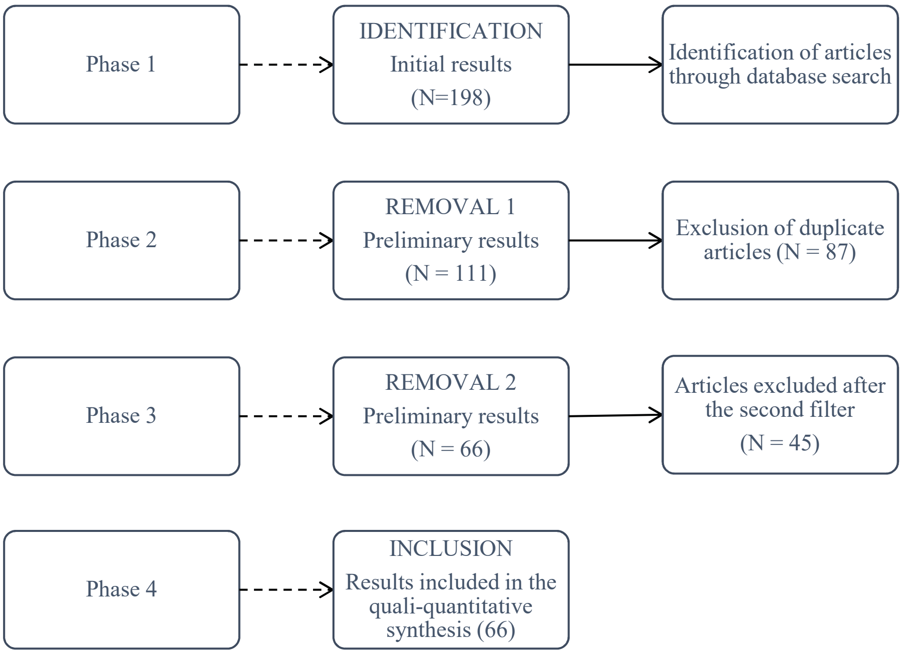

Figure 1: Flow diagram of the information through the different phases of the systematic review procedure
Figura 1: Diagrama de flujo de la información a través de las diferentes fases del procedimiento de revisión sistemática.

Phase 1 - Identification and selection of databases

Specific and multidisciplinary databases were consulted, namely: Agricola, Science Direct, Scielo, Google Scholar, Scopus and Web of Sciences. The search equation was constituted from the terms “leaf area” AND “non-destructive estimation” AND “fruit”, NOT “cereal”, NOT “vegetable”, NOT “ornamental”, NOT “medicinal”, taking into account that the latter are not precise descriptors of the object of study addressed here. The search covered research published between January 2000 and January 2020. This decision on temporality was due to the fact that other publications (Demirsoy, 2009, Khan *et al*., 2016) had already analyzed the previous scientific production. Only articles published in academic journals were considered, disregarding books and chapters, doctoral theses, presentations at conferences, popular science magazines, newspapers and commercial publications.

Phase 2 - Exclusion of duplicate articles and filtering the initial results

The initial results were exported to the EndNote X.7 software package for processing. First, a filter was carried out to identify duplicate results. The resulting articles were examined from the information contained in the fields title, abstract, keywords, type of article, publication date and language. As a result of this analysis, a second filtering process was carried out, excluding brief reports, conference proceedings, letters, essays and works written in languages other than English, Spanish or Portuguese.

Phase 3 - Analysis of preliminary results

The remaining articles were qualitatively analyzed. The inclusion criteria adopted in this instance were established based on three axes: (a) measured variables (leaf length, leaf width, etc.); (b) measurement instruments used (millimetric ruler, leaf area meter, etc.); (c) estimation model proposed. As a result of this analysis, publications were eliminated which, even having the terms “leaf area” and “non-destructive estimation” among their descriptors, titles and abstracts, measured variables such as leaf dry weight; they used sophisticated and unusual measuring instruments, and implemented methodologies to estimate leaf area that were not available since the beginning of this century, such as artificial neural networks.

Phase 4 - Quantitative-qualitative synthesis of articles included

The 66 publications selected through the filtering processes were analyzed in order to achieve the proposed objectives. For this purpose, a database was created with the following categories: (a) common and scientific name of the fruit tree; (b) variety / cultivar; (c) type of proposed model (simple linear, quadratic, cubic, exponential, polynomial); (d) R2 value; (e) bibliographic reference; (f) continent / country where the study was developed; (g) year of publication of the article; (h) variables measured to develop the model (leaf width, leaf height, central nervure length, lateral nervure length, mean primary leaf area per shoot, number of leaves, age of plants, etc.); (i) measuring instrument used to estimate leaf area; (j) validation of the model in the same study.

RESULTS

Next, the general characteristics of scientific production on non-destructive methods of leaf area estimation in fruit trees are presented and analyzed. Table 1 presents the fo

Table 1. Studies comprising the bibliographic portfolio analysis (N = 66)
Tabla 1. Estudios que integran el portfolio bibliográfico analizado (N = 66)

Common/ scientific name	Variety	Model	R^2	Reference
Almond (*Prunus dulcis* (Miller) DA Webb.)	General	LA= 0.9397 (L x N) - 2.028	0.91	Spann and Heerema, 2010
Apple (*Malus domestica* Borkh)	Royal Gala; Fuyi Suprema	LA= 0.6962 (L x W)	0.99	Bosco *et al*., 2012
Apple (*Malus domestica* Borkh)	General	LA= 1.120301 + 0.615 (L x W)	0.98	Kishore *et al*., 2012
Apple (*Malus domestica* Borkh)	Generos	LA= 0.9602 (L x W) + 2.3472	0.98	Sala *et al.,* 2015
Apple (*Malus domestica* Borkh)	Pionier	LA= 0.9652 (L x W) + 1.109	0,99	Sala *et al*., 2015
Apple (*Malus domestica* Borkh)	Jonathan	LA= 1.0022 (L x W) + 0.1051	0.98	Sala *et al.,* 2015
Apple (*Malus domestica* Borkh)	Florina	LA= 1.0066 (L x W) + 0.0229	0.98	Sala *et al*., 2015
Apple (*Malus domestica* Borkh)	Delicious de Voinesti	LA= 0.9726 (L x W) + 1.1748	0.99	Sala *et al*., 2015
Apricot (*Prunus armeniaca* L.)	General	LA= 1.193 + 0.668 (L x W)	0.98	Cirillo *et al*., 2017
Avocato (*Persea americana* L.)	General	LA= -4.555 + 0.934 (L x W)	0.97	Calderón *et al*., 2009
Avocato (*Persea americana* L.)	General	LA= 8.2203 + 0.42241 (L x W)	0.81	Chattopadhyay *et al*., 2011
Banana (*Musa paradisiaca* L.)	General	LA= L x W x 0.80 x N x 0.662	0.99	Kumar *et al.,* 2002
Banana (*Musa paradisiaca* L.)	Prata Ana	LA= 0.5187 (L x W x N) + 9603.5	0.89	Zuculoto *et al*., 2008
Blueberry (*Vaccinium myrtillus* L.)	General	LA= (-0.5095) + [(0.6636 x W^2)] + [(0.1801 x L^2)] + [0.0033 x C^2)]	0.97	Celik *et al*., 2011
Blueberry (*Vaccinium corymbosum* L.)	Sharp Blue	LA= 0.0075 $(L x W)^2$ + 0.3321 (L x W) + 2.2104	0.94	Cabezas Gutiérrez and Peña Baracaldo, 2012
Blueberry (*Vaccinium corymbosum* L.)	General	LA= 0.54 + 0.68 (L x W)	0.97	Fallovo *et al*., 2008
Chestnut (*Castanea sativa* Mill.)	General	LA= 3.36 + 0.11 L^2 – 0.26 L^2 /W^2 + 1.1 W^2	0.99	Serdar and Demirsoy, 2006
Citrus (*Citrus*)	General	LA= 0.680 (L x W) – 0.103	0.99	Mazzini *et al*., 2010
Cocoa (*Teobroma cacao* L.)	CCN51, EET8, IMC67, TCH565	LA= $\beta_0 + \beta_1 L + \beta_2 W + \beta_3 L^2 + \beta_4 \times W + e_i$	0.98	Suárez Salazara *et al*., 2018

Table 1: Continuation
Tabla 1: Continuación.

Coconut (*Cocos nucifera* L.)	General	LA= $0.8282 (L \times W)^{1.5662}$	0.95	Fernandes de Sousa *et al.*, 2005
Coffee (*Coffea arabica* L.; *Coffea canephora* P.)	General	LA= $0.6626 (L \times W)^{1.0116}$	0.99	Antunes *et al.*, 2008
Coffee (*Coffea arabica* L.)	Castillo	LA= $0.99927 \times [L \times (0.14757 + 0.60986 \times W)]$	0.99	Unigarro-Muñoz *et al.*, 2015
Coffee (*Coffea canephora* P.)	General	LA= $0.6723 + 0.6779 (L \times W)$	0.96	Schmildt *et al.*, 2015
Custard apple (*Annona squamosa* L.)	General	LA= $0.72 (L \times W)$	0.77	Lima Silva *et al.*, 2004
Durian (*Durio zibethinus* L.)	CHES-D-I; D-II; D-III; D-IV	LA= $0.888 (L \times W) - 4.961$	0.91	Kumar *et al.*, 2017
Fig (*Ficus carica* L.)	General	LA= $0.963 (L \times W) - 0.0007 (L \times W)^2 + 8.5860^{-10-7} (L \times W)^3$	0.99	Casierra-Posada *et al.*, 2007
Fig (*Ficus carica* L.)	Roxo de Valinhos	LA= $2{,}879 \times L^{1.5451}$	0.87	Souza *et al.*, 2014
Grape (*Vitis vinifera* L.)	Cencibel	LA= $0.587 (L \times W)$	0.99	Montero *et al.*, 2000
Grape (*Vitis vinifera* L.)	Niagara	LA= $0.637 (W)^{1.995}$	0.98	Williams and Martinson, 2003
Grape (*Vitis vinifera* L.)	De Chaunac	LA= $0.672 (W)^{1.963}$	0.96	Williams and Martinson, 2003
Grape (*Vitis vinifera* L.)	Aragonez syn Tempranillo	LA= $49{,}1936 + 0.9958 \times MLA$	0.97	Lopes and Pinto, 2005
Grape (*Vitis vinifera* L.)	Cabernet-Sauvignon	LA= $18.379 \times L - 151.41$	0.97	Tsialtas *et al.*, 2008
Grape (*Vitis vinifera* L.)	Merlot	LA= $-0.001 CNL^2 + 1.462 CNL - 13.551$	0.97	Borghezan *et al.*, 2009
Grape (*Vitis vinifera* L.)	Sauvignon Blanc	LA= $1.0968 LNL^{2.1628}$	0.93	Borghezan *et al.*, 2009
Grape (*Vitis vinifera* L.)	Cavernet Sauvignon	LA= $1.1265 LNL^{2.0445}$	0.94	Borghezan *et al.*, 2009
Grape (*Vitis vinifera* L.)	General	LA= $0.465 + 0.914 (L \times W)$	0.98	Buttaro *et al.*, 2015
Guava (*Acca sellowiana* Berg. Burret)	General	LA= $0.868 (L \times W) - 0.007 (L \times W)^2 + 0.0001 (L \times W)^3$	0.99	Casierra-Posada *et al.*, 2007
Guava (*Psidium guajava* L.)	Paluma	LA= $0.011 (L \times W)^2 + 1.938 (L \times W) + 6.401$	0.99	Da Vitória *et al.*, 2018
Hazelnut (*Corylus avellana* L.)	General	LA= $2.59 + 0.74 (L \times W)$	0.98	Cristofori *et al.*, 2007
Kiwifruit (*Actinidia chinensis* Planch.)	Bruno; Hayward seedling; Matua; Tomuri; Hayward.	LA= $124.56 - (18.3 \times L) - (14.68 \times C) + 1.26 (L \times W) - [0.011 \times (L^2 \times W \times C)] + [0.23 \times (L \times W \times C)] - 0.18 \times W^2$	0.97	Zenginbal *et al.*, 2007
Kiwifruit (*Actinidia deliciosa* A. Chev.)	Hayward	LA= $0.82 (L \times W) - 0.28$	0.99	Mendoza-de Gyves *et al.*, 2007
Loquat (*Eriobotrya japónica* L.)	General	LA= $1.81 + 0.68 (L \times W)$	0.98	Mendoza-de Gyves *et al.*, 2008

Table 1: Continuation

Tabla 1: Continuación.

Loquat (*Eriobotrya japónica* L.)	General	LA= -0.516 + 0.667 (L x W)	0.98	Teobaldelli *et al*., 2019
Macadamia (*Macadamia integrifolia* Maiden & Betche)	Haes 344	LA= 1.6635 + 0.6968 (L x W)	0.96	Schmildt *et al*., 2016
Mango (*Mangifera indica* L.)	Seedling	LA= 0.2452 (L x W) x N	0.87	Ghoreishi *et al*., 2012
Mango (*Mangifera indica* L.)	Tommy Atkins	AF = 0,000001$(L \times W)^3$ - 0,00059 $(L \times W)^2$ + 0,77 (L x W) - 0,462	0.97	De Lima *et al*., 2012
Mango (*Mangifera indica* L.)	General	LA= -0.3635 + 0.7961 (L x W)	0.92	Calderón *et al*., 2009
Muskmelon (*Cucumis melo* L.)	Gold Mine	LA= 0.826 x $L^{1.89}$	0.97	Nascimento *et al*., 2002
Muskmelon (*Cucumis melo* L.)	Chioumith	LA= 0.73 (L x W)	0.99	Wu *et al.,* 2010
Muskmelon (*Cucumis melo* L.)	Zhufen	LA= 0.65 (L x W)	0.99	Wu *et al.,* 2010
Muskmelon (*Cucumis melo* L.)	Tianhun	LA= 0.67 (L x W)	0.99	Wu *et al.,* 2010
Blackberry (*Rubus fruticosus* L.)	General	LA= 0.90 + 0.70 (L x W)	0.97	Fallovo *et al*., 2008
Blackberry (*Rubus glaucus* L.)	General	LA= 0.637 (L x W) + 0.0001 $(L \times W)^2$ - 1.875^{-10-6} $(L \times W)^3$	0.99	Casierra-Posada *et al*., 2007
Nakai (*Pyrus pyrifolia* Burm F.)	General	LA= 3.804 (L x N) - 39.80	0.93	Spann and Heerema, 2010
Olive (*Olea europea* L.)	General	LA= 0.308 + 0.780 (L x W)	0.94	Koubouris *et al*., 2018
Olive (*Olea europea* L.)	General	LA= 0.427 (L x N) + 6.538	0.92	Spann and Heerema, 2010
Passion fruit (*Passiflora edulis* L.)	Alata	LA= -3.70 + 0.78	0.98	Morgado *et al*., 2013
Passion fruit (*Passiflora edulis* L.)	Coccinea	LA= -0.70 + 0.82	0,99	Morgado *et al*., 2013
Passion fruit (*Passiflora edulis* L.)	Giberti	LA= -2.00 + 0.41	0.93	Morgado *et al*., 2013
Passion fruit (*Passiflora edulis* L.)	Ligulares	LA= -4.98 + 0.88	0.95	Morgado *et al*., 2013
Passion fruit (*Passiflora edulis* L.)	Misera	LA= -1.94 + 0.72	0.94	Morgado *et al*., 2013
Passion fruit (*Passiflora edulis* L.)	Micronata	LA= 0.73 + 0.75	0.96	Morgado *et al.,* 2013
Passion fruit (*Passiflora edulis* L.)	Sebacea	LA= 1.17 + 0.79	0.98	Morgado *et al.,* 2013
Passion fruit (*Passiflora edulis* L.)	Nitida	LA= -5.79 + 0.64	0.98	Morgado *et al*., 2013

Table 1: Continuation
Tabla 1: Continuación.

Passion fruit (*Passiflora edulis* L.)	General	LA= 0.25 + 0.64 (L x W) (lanceolate) LA= 4.82 + 0.649 (L x W) (bilobed) LA= - 0.81 + 0.54 (L x W) (trilobed)	0.95	Luna Souto *et al*., 2017
Pawpaw (*Caryca papaya* L.)	Formasa; Solo	Log AF= 0.315 + 1.85 log CNC	0.90	Campostrini and Yamanishi, 2001
Pawpaw (*Caryca papaya* L.)	Maradol roja	LA= -303.0742 + 31.2028 CNC	0.93	Cardona *et al*., 2009
Peach (*Prunus persica* L.)	General	LA= -0.5 + 0.23 x (L / W) + 0.67 (L x W)	0.99	Demirsoy *et al*., 2004
Peach (*Prunus persica* L.)	Jarillo	LA= 1.572 + 0.651 (L x W)	0.99	Quevedo García *et al*., 2012
Peach (*Prunus persica* L.)	BRS Kampai	LA= 6.852 + 0.823 (L x W) – 0.691 W^2 - 1.614 L/W	0.97	Sachet *et al*., 2015
Peach (*Prunus persica* L.)	Dorado	LA= 1.381 (L x W) - 0.012 (L x W)^2 + 0.000 (L x W)^3 - 9.034	0.87	Casierra Posada *et al*., 2017
Peach (*Prunus persica* L.)	Rubidoux	LA= 0.611 (L x W) + 0.000 (L x W)^2 + 2.013	0.96	Casierra Posada *et al*., 2017
Peach (*Prunus persica* L.)	Diamante	LA= 1.186 (L x W) - 0.008 (L x W)^2 + 0.000 (L x W)^3 - 7.880	0.93	Casierra Posada *et al*., 2017
Peach (*Prunus persica* L.)	Rey Negro	LA= 0.582 (L x W) + 0.001 (L x W)^2 + 2.356	0.91	Casierra Posada *et al*., 2017
Pear (*Pyrus communis* L.)	General	LA= 0.922581 + 0.660898 (L x W)	0.99	Kiseleva, 2017
Pecan nut (*Carya illinoinensis* L.)	General	LA= 1.95 + 0.60 (L x W)	0.93	Torri *et al*., 2009
Pecan nut (*Carya illinoinensis* L.)	Wichita	LA= 4.898 (L x N) - 127.5	0.93	Spann and Heerema, 2010
Persimmon (*Diospyros kaki* L.)	Haes 344	LA= 3.83 + 0.96 (L x W)	0.98	Cristofori *et al.,* 2008
Pineaple (*Ananas comosus* L. Merr)	Vitoria	LA= 19.298 (L x W) - 559.9	0.94	Francisco *et al*., 2014
Pineaple (*Ananas comosus* L. Merr)	Perola	LA = -214.727 + (2.938 x L) + (74.329 x W)	0.97	Pereira dos Santos *et al*., 2018
Pistachio (*Pistacia vera* L.)	Badami	LA= 76.97 (L x W) + 35.985	0.98	Karimi *et al*., 2009
Pistachio (*Pistacia vera* L.)	Kerman	LA = 8.814 (L x N) - 85.53	0.85	Spann and Heerema, 2010
Plum (*Prunus salicina* Lindell)	Gold Fruly	LA= -0.354 (L x W) + 0.008 (L x W)^2 + 25.607	0.77	Casierra Posada *et al.,* 2017
Plum (*Prunus salicina* Lindell)	Ecuatoriano	LA= 0.488 (L x W) + 0.001 (L x W)^2 + 4.772	0.83	Casierra Posada *et al*., 2017
Plum (*Prunus salicina* Lindell)	Methley	LA= -0.104 (L x W) + 0.010 (L x W)^2 + 14.458	0.62	Casierra Posada *et al*., 2017
Plum (*Prunus salicina* Lindell)	Horvin	LA= -0.236 (L x W) + 0.050 (L x W)^2 - 0.000 (L x W)^3 + 5.983	0.83	Casierra Posada *et al*., 2017

Table 1: Continuation
Tabla 1: Continuación.

Pomegranate (*Punica granatum* L.)	Bhagwa	LA= -0.0477 + 0.0282 x L + 0.0842 x W + 0.965 (L x A)	1.00	Meshram *et al.*, 2012
Pomegranate (*Punica granatum* L.)	General	LA= 0.851 (L x W)	0.99	Shabani and Sepaskhah, 2017
Raspberry (*Rubus idaens* L.)	General	LA= 0.03 + 0.71 (L x W)	0.97	Fallovo *et al.*, 2008
Redcurrant (*Ribes rubrum* L.)	General	LA= 1.72 + 0.69 (L x W)	0.97	Fallovo et al., 2008
Strawberry (*Fragaria vesca* L.)	General	LA= 1.89 + 2.145 x (upper lobe length) x (left lobe width)	0.99	Demirsoy *et al.*, 2005
Sweet cherry (*Prunus cerasus* L.)	Early Burlat; Ziraat; Bing; Van; Lambert; Stella, etc.	LA= -22.45 + 2.59 x W + 4.76 x L + 0.36 x C – 0.23 x L^2 + 0.034 $(W \times L)^2$ - 0.002 x C x L^2	0.96	Demirsoy and Demirsoy, 2003
Sweet cherry (*Prunus avium* L.)	Bing; Van; Lapins	LA= 0.6612 (L x W)	0.99	Cittadini and Peri, 2006
Sweet cherry (*Prunus avium* L.)	Regina	LA= 6.84 - 2.36 x L + 0.14 L^2 - 0.016 x W x L^2 + 0.84 L x W x L	0.98	Demirsoy and Lang, 2010
Tomato (*Solanum lycorpersicum* L.)	Facundo	LA= -8.75 $(L \times W)^2$ + 10.43 (L x W) -1.44	0.88	Blanco and Folegatti, 2003
Tomato (*Solanum lycorpersicum* L.)	Jama	LA= -10.12 + 0.834 (L x W)	0.88	Carmassi *et al.*, 2007
Uchuva (*Physalis peruviana* L.)	General	LA= 0.728 (L x W) - 0.001 $(L \times W)^2$ + 8.600^{-10-5} $(L \times W)^3$	0.99	Casierra-Posada *et al.*, 2007
Walnut (*Juglans regia* L.)	General	LA= 1.11 + 0.69 (L x W)	0.99	Keramatlou *et al.*, 2015
Walnut (*Juglans regia* L.)	General	LA= 7.770 (L x N) - 8.994	0.86	Spann and Heerema, 2010
Watermelon (*Citrillus lanatus* Thumb.)	General	LA= 2.99 + 0.50 (L x W)	0.98	Rouphael *et al.*, 2010
White mulberry (*Morus alba* L.)	General	LA= 0.973 (L x W) - 0.735	1.00	Pandey and Singh, 2011

General: for all cultivars belonging to the specie; LA= leaf area; L= leaf length; W= leaf width; C= cultivar; N= total number of leaves plant; CNL= central nervure length; LNL= lateral nervure lengt h; MLA= mean primary leaf area per shoot (cm^2)

llowing data: scientific and common name of the fruit tree, cultivars analyzed, models developed, regression coefficient obtained, and bibliographic reference. The remaining aspects are discussed qualitatively or quantitatively.

Table 1 shows that non-destructive estimation models of leaf area have been developed in the last 20 years for more than 40 fruit plants and for almost 90 different cultivars. Linear models (62%) predominate over polynomials (25%) and exponentials (13%) models, with high regression rates (varying from 0.77 to 1.00) which indicates the goodness of fit of the proposed models. Regarding the origin of the studies, it is observed that South America is the region in which the most research (51%) have been conducted during the period considered, followed by Asia, Europe and North America, in that order. A detailed analysis shows that Brazil emerges as the country in South America where the greatest number of investigations have been carried out (45%), leaving the remaining 6% distributed among Colombia, Argentina, Cuba and Costa Rica. In Asia, India and Iran stand out as prolific countries (27%) in the production of scientific knowledge on the subject, while Europe and North America together represent 22% of the total.

With respect to the periodicity of the publications it is observed that the research has developed in a markedly irregular way. In this sense, an upward trend has been observed since the beginning of the 21st century, reaching its maximum level in 2012. This boom the publications was followed by a saw-type distribution with peaks corresponding to the years 2015 and 2017. In the last two years, there has been a significant drop in the number of publications on the subject.

When the strictly operational aspects of the articles that make up the portfolio studied are considered, it is noted that regarding the variables measured, the length and width of the leaves (84%) predominate; regarding measuring instruments used, protrude portable leaf area meter, type LI-COR, model 3000 or 3100 (41%); in turn, Excel, SAS and SPSS emerge as the main computer programs used for the calculation of the regression equations and the development of the models. Finally, it should be noted that there is a very important percentage of studies (77.50%) that have validated the model, either with a new sample of the same fruit trees or with different cultivars to those used to develop the model.

DISCUSSION

The general objective of the study was to provide a systematic review of articles on non-destructive estimation of leaf area in fruits, published between January 2000 and January 2020. For this purpose, a bibliographic portfolio, composed of 66 scientific articles that responded to the defined search profile, was examined. The detailed analysis of the selected articles offers an overview of the most recent scientific evidence on this problem, being able to become a reference material for technicians, professionals and researchers interested in this subject. Because it is a descriptive-retrospective work, the study carried out includes the main trends that have characterized the published research on non-destructive estimation of leaf area in fruits during the last 20 years, which can be summarized as follows:

a. most of the studies have been carried out in emerging or developing countries. Possibly because they are relatively inexpensive studies, which do not require sophisticated instruments or facilities equipped with the latest technology,

b. models have been developed for almost all fruit crops, from the most popular to the least traditional, such as durian (Kumar *et al*., 2017). What gives horticultural researchers a considerable competitive advantage to the equip them with simple and reliable methods to measure leaf area in a non-destructive way,

c. most models developed employing as input variables proxy such as the length and/or width of leaves (Rouphael *et al*., 2010). In all cases, these are simple and non-destructive methodologies that preserve the canopy, allowing the reuse of the same leaves. This also makes it easier to measure the leaf area of the same plants during the growth process (Kalacska *et al*., 2005),

d. in general terms, the proposed models are based on simple equations, which can be calculated with statistical resources available to all users. This transforms them into ductile tools, easy to handle and reliable when making decisions,

e. finally, it is noteworthy that almost all the models analyzed in this review have been validated within the same study. This gives them a strong consistency between the observed and estimated leaf area, increasing prediction accuracy.

CONCLUSSION

Leaf area is a key parameter in various agronomic processes and physiological studies (Fanourakis et al., 2016). Among other aspects, it plays a key role on the size and filling of the fruit (Keramatlou *et al*., 2015). For this reason, having simple, accurate and inexpensive methodologies to estimate the foliar area is key in the physiology of fruit trees. This study presents a review of 66 models, developed around the world during the last 20 years, to measure the foliar area in fruit crops in situ and in a non-invasive or non-destructive way. It is expected to constitute a useful contribution to technicians, academics and researchers interested in this topic.

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