# IDENTIFICATION AND QUANTIFICATION OF PERSIAN LIME (*Citrus latifolia* TANAKA) LOSSES IN PACKINGHOUSES: CASE STUDY IN CUITLÁHUAC, VERACRUZ, MEXICO

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*SUMMARY*

*Losses of fruit and vegetable products occur from the fields to the exit of the product from company facilities. The objective of this research was to identify the reasons why Persian lemons (*Citrus latifolia *Tanaka) are discarded in packinghouses located in the municipality of Cuitláhuac, Veracruz, Mexico, as well as the destination of the discarded product, and to quantify these losses through the application of a survey. A study area was established, and a list of packinghouses in the municipality of Cuitláhuac, Veracruz registered with the National Service for Agrifood Health, Safety and Quality (SENASICA), updated on December 16, 2019, was documented. The locations of the listed Persian lime packinghouses were determined using Google Earth; a questionnaire was prepared and applied in the packinghouses. The information obtained was analyzed using Pearson's correlation coefficient, a principal component analysis and cluster analysis. The Persian lime losses generated in the packinghouses were distributed as follows: 50 % were sent to Persian lime juice extractors located in another municipality in the state of Veracruz, discarded for not meeting the required caliber (size), 14 % were discarded in the fields due to color variation, and the remaining 36 % were thrown on a garbage truck as final disposal due to poor appearance and lack of freshness (inedible waste). The use of surveys made it possible to identify the types of Persian lime losses that occur. It is necessary to develop strategies to reduce lime losses and to treat them in order to minimize their environmental impact.*

## Introduction

Approximately 30% of the food produced globally is lost at some point in the food supply chain, causing serious economic, environmental and social problems (Xu *et al*., 2018). According to the Food and Agriculture Organization of the United Nations (FAO, 2011), food losses occur during the initial stages of the food supply chain, from primary production to industrial processing, while food waste refers to that which occurs during the final retail sale and consumption stages.

Specifically, global food losses are estimated at 13.8%, equivalent to 400 million dollars; however, their reduction requires economic and time investments that are often estimated to exceed the benefits (United Nations [UN], 2019). UN Sustainable Development Goal (SDG) number 12.3 aims to “halve global per capita food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses” by 2030 (UN, 2020).

The main causes of food loss in the food industry are: spoilage, damage, poor demand forecasting, overproduction, inefficient management, exogenous factors (weather, seasonal effects, supply and demand, etc.), processing problems, contamination and inappropriate packaging. Identified barriers to reducing food loss and waste reduction include a lack of data, an unclear definition of food loss and waste, a lack

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## IDENTIFICACIÓN Y CUANTIFICACIÓN DE PÉRDIDAS DE LIMA PERSA (*Citrus Latifolia* TANAKA) EN EMPACADORAS: ESTUDIO DE CASO EN CUITLÁHUAC, VERACRUZ, MÉXICO

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*RESUMEN*

*Las pérdidas de productos hortofrutícolas son generadas desde los campos de cultivo hasta la salida del producto en las empresas. El objetivo de esta investigación fue identificar las razones por las que se descarta al limón persa (*Citrus latifolia *Tanaka) en empacadoras ubicadas en el municipio de Cuitláhuac, Veracruz, México, así como el destino del producto descartado y la cuantificación de estas pérdidas mediante la aplicación de una encuesta. Se estableció un área de estudio, y se documentó una lista de empacadoras del municipio de Cuitláhuac, Veracruz registradas en el Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria (SENASICA) actualizada el 16 de diciembre de 2019. Se determinó la ubicación de las empacadoras de limón persa enlistadas empleando Google Earth; se elaboró un cuestionario y se aplicó en las empacadoras. La información obtenida se analizó mediante el coeficiente de correlación de Pearson, un análisis de componentes principales y un análisis de clusters. Las pérdidas de limón persa que se generan en las empacadoras se distribuyen de la siguiente manera: 50% se envía a extractoras de jugo de limón persa ubicadas en otro municipio en el estado de Veracruz, descartados por no cumplir con el calibre (tamaño), 14% se tira a los campos de cultivo debido a la variación de color y el 36 % restante se destina al camión de basura como disposición final por mala apariencia y falta de frescura (residuos no comestibles). El uso de encuestas permitió identificar los tipos de pérdidas de limón persa que se generan. Es necesario desarrollar estrategias para reducir las pérdidas de limón y brindar un tratamiento a estas pérdidas para minimizar su impacto al medio ambiente.*

## IDENTIFICAÇÃO E QUANTIFICAÇÃO DE PERDAS DE LIMA DA PÉRSIA (*Citrus Latifolia* TANAKA) EM EMPACOTADORAS: ESTUDO DE CASO EM CUITLÁHUAC, VERACRUZ, MÉXICO

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*RESUMO*

*As perdas de produtos hortifrutícolas ocorrem desde os campos até a saída do produto das instalações da empresa. O objetivo desta pesquisa foi identificar as razões pelas quais os limões persas (*Citrus latifolia *Tanaka) são descartados em empacotadoras localizadas no município de Cuitláhuac, Veracruz, México, bem como o destino do produto descartado, e quantificar essas perdas por meio da aplicação de uma pesquisa. Foi estabelecida uma área de estudo e documentada uma lista de casas de embalagem no município de Cuitláhuac, Veracruz, registrada no Serviço Nacional de Saúde, Segurança e Qualidade Agroalimentar (SENASICA), atualizada em 16 de dezembro de 2019. Os locais dos empacotadores de lima da Pérsia listados foram determinados usando o Google Earth; um questionário foi preparado e aplicado nos empacotadores. As informações obtidas foram analisadas usando o coeficiente de correlação de Pearson, uma análise de componentes principais e uma análise de agrupamento. As perdas de limões persas geradas nas casas de embalagem foram distribuídas da seguinte forma: 50% foram enviados para extratores de suco de limões persas localizados em outro município do estado de Veracruz, descartados por não atenderem ao calibre (tamanho) exigido, 14% foram descartados nos campos devido à variação de cor, e os 36% restantes foram jogados em um caminhão de lixo como disposição final devido à má aparência e à falta de frescor (resíduos não comestíveis). O uso de pesquisas possibilitou a identificação dos tipos de perdas de limões persa que ocorrem. É necessário desenvolver estratégias para reduzir as perdas de cal e tratá-las a fim de minimizar seu impacto ambiental.*

of public awareness, underestimation of the hidden costs of unsustainability, and global negative ecological impacts that are not representative of the economic impacts of each stakeholder (Lemaire and Limbourg, 2019).

According to the FAO (2017), citrus is one of the most abundant fruit genera in the world and global citrus production increased by 20.6% from 2006 to 2016, amounting to 132.4 million tons. Mexico is the leading Persian lime (*Citrus latifolia* Tanaka) producing country in the world, and 60% of the Persian lime area is concentrated in Veracruz. In particular, the citrus area of Cuitláhuac, Veracruz, annually produces more than 4.54 × 107 kg of Persian lime (Bulbarela-Marini *et al*., 2019).

One of the main advantages of growing Persian lime is that, due to the region's climate, it can be harvested throughout the year with the highest production occurring between May and August. The fruit must meet all food quality standards outlined in the 'Specifications for the use of the Official Mexican Supreme Quality Brand for Persian Lime' (SAGARPA, 2004), including color, size, and export requirements. Packinghouses are responsible for ensuring compliance with these standards. Adherence to these standards creates an environment conducive to economic development in the region. Additionally, interest in business creation is increasing due to the demand for exporting products to different countries.

One of the main disadvantages of creating more Persian lime packing companies is the high volume of losses generated by not meeting established quality standards. In addition to the economic losses, citrus waste that is discarded and taken to landfills cause environmental problems, such as unpleasant odors and leachates, in addition to which this waste attracts flies and rats due to its low pH, high water content and high organic matter content (Eryildiz *et al*., 2020).

Postharvest loss data in developing countries may be overestimated, or not quantified (Priefer *et al*., 2016). This lack of data on Persian lime loss is one of the obstacles impeding the study of this problem and the formation of possible solutions. Hanson *et al*. (2016) propose ten methods for quantifying food loss and waste (FLW), seven of which focus on measurement or approximation, such as; direct weighing, counting, volume assessment, waste composition analysis, records, diaries and surveys. On the other hand, there are inference quantification methods that involve calculation, such as mass balances, modelling and the use of indirect data.

The aim of this study was to quantify the losses of Persian lime in packing houses in the central region of the state of Veracruz, Mexico, and to determine the disposal or management of the discarded lime. The obtained information is expected to be useful in finding solutions to the problem of discarding by-products from the Persian lime industry, which will benefit the product system's economy and the region's environment.

## Materials and Methods

The research was carried out in the January-March 2020 period in the municipality of Cuitláhuac, Veracruz, Mexico (Figure 1). The Persian lime (*Citrus latifolia* Tanaka) packinghouses were located at coordinates 18°49"North latitude and 96°43"West longitude

The study was divided into three stages. The first stage focused on documenting the list of packinghouses in the municipality of Cuitláhuac, Veracruz, Mexico. The study population was defined using as a reference the document entitled Authorized packinghouses of Persian lime for export and national mobilization registered in the National Service for Agrifood Health, Safety and Quality (SENASICA, 2019). For the geographical location of the packinghouses, the spatial positioning and georeferencing technique was used by means of Google Earth version 7.3 software.

The second stage consisted of designing and validating a survey as an instrument to collect information from the packinghouses. The survey was divided into three sections. 1) respondent data: name, position held, company name and address; 2) Persian lime quality: company size, production volume in low and high season, and product destination (domestic and/or international market); 3) Persian lime loss management: name of the product that is not sold, characteristics of the product that is not sold, amount of Persian lime losses, use given to the Persian lime loss, sale of the losses generated and to whom, and, lastly, price of the Persian lime losses. For the validation of the questionnaire, preliminary tests were carried out with two packinghouses.

The third stage consisted of applying the survey to specialists and technicians responsible for the packinghouses. The following variables were considered: tons of raw material entering the packinghouse (tonrm), tons of waste leaving the packinghouse (tonwaste), waste sent to juice extractors (juiceextractorton), waste sent to crop fields (fieldton), waste sent to landfill (landfillton), Persian limes sold to the domestic and international markets (dom&int), company size (companysize), fruit color (color) and size (size) characteristics to be met, harvesting time (freshness), previous selection (selection), another way of selection (appearance), sum of all quality attributes (qualtotal), final destination of the waste generated (finaldisp) and sale of the waste (wastesale).

*Statistical analysis*

Statistical analysis was performed on the data obtained from both seasons together. Pearson's correlation coefficient (P<0.05) was applied to determine the statistical relationship between the variables. Additionally, a hierarchical cluster analysis of average linkage (dendrogram) and a principal component analysis (PCA) were performed. For this, Statistical Analysis System (SAS 9.0) software was used.

## Results and Discussion

Loss of fruit and vegetables is the main cause of the water footprint in the global supply chain, responsible for 20% (Agnusdei *et al*., 2022). Kuiper and Cui (2021) found that fruit and vegetable losses have a strong impact on food security and the environment, especially in low-income regions.

In the present study, a survey was conducted in 14 out of 28 (due to the accessibility and availability of information) Persian lime packinghouses registered with SENASICA as of December 19, 2019. Of the total number of respondents, 50% were men and 50% were women. Based on the information provided (company name and address), the packinghouses were located on the map using Google Earth; 71% are located in the center of the municipality and 29% are located on the outskirts of the urban area.

Carrillo Ahumada and Herrera Morales (2011) note that in the central region of the state of Veracruz, in municipalities such as Cuitláhuac, Cotaxtla, Carrillo Puerto, Yanga, and Paso del Macho, Persian limes are received from

Figure 1. Location of Cuitláhuac, Veracruz. File: Central Mexico WV map PNG.png by Ypsilon from Finland is marked with CC0 1.0.

municipalities in the state of Veracruz, as well as from other states in the country, such as Oaxaca, Tabasco, and Yucatán. The raw materials are transported in open five-ton trucks within the state, and in 30-ton trucks when they are transported from another state.

According to the surveys conducted in this study, the packinghouses in Cuitláhuac operate from Monday to Saturday and receive raw material regularly from Wednesday to Saturday. The surveyed packinghouses operate in two seasons; the first is the high season, which lasts from May to October, and the second is the low season, which lasts from November to April. The product is sold to national and international markets, mainly to the United States.

Table I shows the amount of raw material received and losses generated per day in the surveyed packinghouses, as well as their final disposal. The last column shows the relationship between Persian lime losses and the amount of raw material received, expressed as a percentage of losses generated per day (Garcia-Garcia *et al*., 2019). It can be seen that the packinghouse that generates the highest percentage of lime loss per day is P1, with 1.88%, while the packinghouses that record the lowest percentages of loss per day are those that receive the highest quantities of limes (P5, P6 and P7), which shows a meticulous selection of the fruit from the time it is received until it leaves the agroindustry.

From the Principal Component Analysis, three components were extracted which explain 71% of the total variability of Persian lime waste from the 14 packinghouses surveyed (Table II).

The first loss of Persian lemons is sent to the juicers, whose cost ranges from 20 to 50 pesos per 18kg box (1.11 to 2.77pesos/kg), and is considered a second quality lemon in the agribusiness. Table III shows the matrix of principal components obtained from the

TABLE I
RELATIONSHIP OF ENTRY (INPUT) AND LOSSES OF PERSIAN LIMES IN PACKINGHOUSES IN CUITLÁHUAC, VERACRUZ

| Packinghouse code | Raw material (ton/day) | Waste generate (ton/day) | Final disposal of lime losses | | | Loss/day (%) |
|---|---|---|---|---|---|---|
| | | | Juice extractor (ton/day) | Field (ton/day) | Garbage (ton/day) | |
| P1 | 8.1 | 0.153 | 0.153 | 0 | 0 | 1.88 |
| P2 | 25.2 | 0.144 | 0 | 0 | 0.144 | 0.57 |
| P3 | 7.2 | 0.09 | 0.09 | 0 | 0 | 1.25 |
| P4 | 25.2 | 0.153 | 0 | 0 | 0.153 | 0.60 |
| P5 | 99 | 0.252 | 0.252 | 0 | 0 | 0.25 |
| P6 | 90 | 0.153 | 0.153 | 0 | 0 | 0.17 |
| P7 | 90.9 | 0.18 | 0 | 0.180 | 0 | 0.19 |
| P8 | 43.2 | 0.189 | 0.189 | 0 | 0 | 0.43 |
| P9 | 49.5 | 0.162 | 0 | 0 | 0.162 | 0.32 |
| P10 | 45 | 0.162 | 0 | 0.162 | 0 | 0.36 |
| P11 | 54 | 0.207 | 0.207 | 0 | 0 | 0.38 |
| P12 | 49.5 | 0.162 | 0 | 0 | 0.162 | 0.32 |
| P13 | 34.2 | 0.153 | 0.153 | 0 | 0 | 0.44 |
| P14 | 54 | 0.144 | 0 | 0 | 0.144 | 0.26 |

TABLE II
EIGENVALUES OF THE CORRELATION MATRIX OBTAINED

| No. | Eigenvalue | Difference | Proportion | Cumulative |
|---|---|---|---|---|
| 1 | 5.4107 | 2.0052 | 0.3607 | 0.3607 |
| 2 | 3.4054 | 1.3923 | 0.2227 | 0.5878 |
| 3 | 2.0131 | 0.3354 | 0.1342 | 0.722 |
| 4 | 1.6776 | 0.7122 | 0.1118 | 0.8338 |
| 5 | 0.9653 | | 0.0644 | 0.8982 |

TABLE III
PRINCIPAL COMPONENTS OBTAINED FROM THE VARIABLES CONSIDERED

| | Eigenvalues | | |
|---|---|---|---|
| | PC1 (Size) | PC2 (Color) | PC3 (Appearance and freshness) |
| Tonrm | 0.1999 | 0.2324 | -0.1502 |
| Tonwaste | 0.2909 | 0.1764 | -0.0756 |
| Juiceextratorton | 0.3414 | -0.2746 | -0.1362 |
| Fieldton | 0.0216 | 0.3424 | -0.1346 |
| Landfillton | -0.3054 | 0.1481 | 0.2439 |
| Dom&int | 0.2526 | 0.3334 | 0.0482 |
| Companysize | 0.2336 | 0.0045 | -0.1547 |
| Color | 0.0882 | -0.4335 | 0.3229 |
| Size | 0.3362 | 0.0677 | -0.0552 |
| Freshness | 0.2644 | 0.1234 | 0.4293 |
| Selection | 0.2695 | 0.3032 | 0.1678 |
| Appearance | -0.0043 | -0.1914 | 0.5850 |
| Qualtotal | 0.3347 | 0.1393 | 0.3725 |
| Finaldisp | 0.3043 | -0.3070 | -0.1584 |
| Wastesale | 0.2802 | -0.3726 | -0.1522 |

Tonrm: tons of raw material entering the packinghouse; Tonwaste: tons of waste leaving the packinghouse; Juiceextractorton: waste sent to juice extractors; Fieldton: waste sent to crop fields; Landfillton: waste sent to landfill; Dom&int: Persian limes sold to the domestic and international markets; Companysize: company size; color: fruit color; Size: size; Freshness: harvesting time; Selection: previous selection; Appearance: another way of selection; Qualtotal: sum of all quality attributes; finaldisp: final destination of the waste generated; Wastesale: sale of the waste.

analysed variables. The variables juice extractor (0.3414), size (0.3362) and total quality (0.3347) have a high positive influence on the principal component 1, which indicates that the waste sent to juice extractors is mainly that which does not meet the size and total quality characteristics. In this context, Ortíz-Gonzálo *et al*. (2021) found that quality requirements are often associated with the generation of food losses and waste. Similarly, O'Connor *et al*. (2022) found that unsaleable produce, which results from fluctuations in consumer demand and also relates to produce that was out of quality specifications (size, shape and physical damage to the product), accounts for 21%.

The color (-0.4335) related to the degree of ripeness, the sale of the waste (-0.3726) and the final disposal of the generated waste (-0.3070) have large negative influences on the principal component 2; this relationship indicates that the color of the lime has an impact on the final destination of the waste and that those limes that do not meet this standard are mainly sold as waste. Garcia-Garcia *et al*. (2017) consider two types of waste according to a nine-stage categorization: inedible, which is used in anaerobic digestion because it is spoiled or severely damaged, and class two products, which do not meet quality standards because they have skin blemishes and discoloration and are sold at reduced prices ranging from 2.8 to 17.2pesos/kg.

Finally, principal component 3 relates limes thrown in the dumpster to those that do not meet the required appearance (0.5850), freshness (0.4293), total quality (0.3725), and color (0.3229) attributes, all of which are related to visual aspects of product acceptance. Garcia-Garcia *et al*. (2019) noted that in the case of Chingford Fruit Ltd, a food company based in London, England, agricultural waste is generated due to growing conditions (fruit size) and quality standards for the sale of the product. This waste is either sent to anaerobic digestion (in the case of inedible waste) or sold at discounted prices.

Figure 2 shows that there are two packinghouses (P8 and P11) that are very careful in terms of raw materials input and losses generated.

Figure 3 shows that four clusters were formed, described from top to bottom. The first one corresponds to packinghouse five (P5), which reported a higher input of raw material compared to the other packinghouses and, therefore, a higher amount of losses generated, which are sold to juice extractors at prices ranging from 20 to 50 pesos per 18kg box. The second cluster is formed by packinghouses ten (P10) and seven (P7), which are related by the amount of waste generated and deposited in the fields. The third cluster is made up of five packinghouses (P14, P9, P4, P12 and P2), which are related to the fact that the limes are deposited in open-air dumps. The fourth cluster consists of six packing houses (P13, P3, P11, P8, P6 and P1), which have the lowest amounts of raw material inputs and the lowest amounts of waste, which are sent to juice extractors for final disposal, accounting for 42.85% of the total.

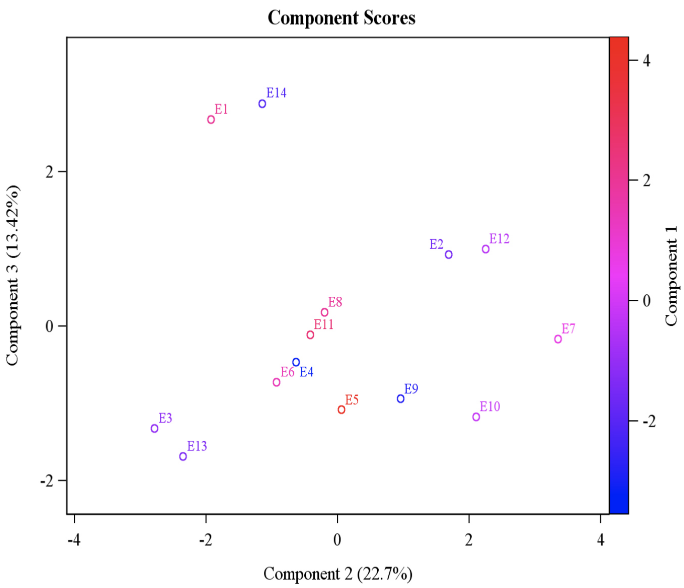

Figure 2. Scores of the three principal components of the surveyed packinghouses.

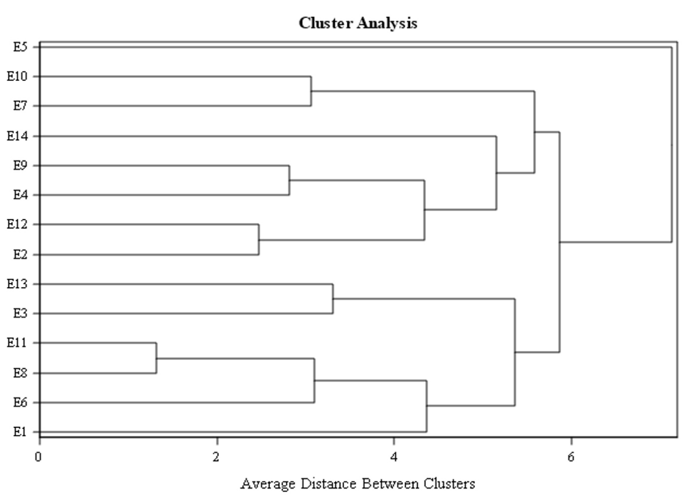

Figure 3. Dendogram of Persian lime packinghouses.

Garcia-Garcia *et al*. (2019) note that the variability of citrus waste generation is high and complex due to factors related to growing conditions and customer demand, making it difficult to make projections of citrus waste generation. In our study, it is clear that most of the Persian lime waste from the Cuitláhuac packinghouses is not used as agro-industrial waste, so it is important to implement proposals to reduce its environmental impact.

## Conclusion

The objective of this study was to quantify the losses of Persian lime in packing houses in the central region of the state of Veracruz, Mexico, and to determine the disposal or management of the discarded lime. The Persian lime (*Citrus latifolia* Tanaka) packinghouses located in the municipality of Cuitláhuac, Veracruz, generate three categories of Persian lime losses. A large portion is sent to juice extractors, another is deposited in the Persian lime cultivation fields without any treatment, and the other third is deposited in the municipal landfill. This negatively impacts the environment and the economy of the packinghouses and the region. Based on the above, it can be concluded that the study's objective was achieved. Therefore, it is important that the packinghouses implement a sustainable model that generates environmental, social, and economic benefits in the region of Cuitláhuac, Veracruz.

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