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ORIGINAL RESEARCH ARTICLE

Evaluation of postharvest loss of oranges (*Citrus sinensis*) in the central jungle of Peru

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ABSTRACT

There are several factors that generate postharvest losses of *Citrus sinensis*, but none have been focused on the central jungle of the Junín region of Peru. The objective of this research was to evaluate postharvest losses of *Citrus sinensis* in the province of Satipo, Junín region of Peru, considering the stages of the production chain. The methodology was applied to descriptive and cross-sectional design. A sample of 10 orange trees, 3 transport intermediaries and 5 traders selected for compliance with minimum volume and quality requirements were used. The °Brix, pH and acidity characteristics of the fruit were determined. Subsequently, absolute and percentage losses were quantified through direct observation, surveys and interviews. The main postharvest losses of *Citrus sinensis* were 1.50% in harvesting and detaching, 1.75% in transport to the collection center, 2.23% in storage and transport by intermediaries, and 2.90% in storage and sale by retailers. The overall loss was 8.12% throughout the production chain and US$5.75 per MT of *C. sinensis* harvested. The main damages found were mechanical and biological, caused by poor harvesting and packaging techniques, precarious storage and careless transport of the merchandise.

Keywords: Orange; Losses; Postharvest; Harvest

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1. Introduction

Satipo is a province located in the central jungle of Peru, within the Junín region, limited between 11°15'00" south latitude and 74°42'00" west longitude. It is located between 800 and 1,500 msnm, an average temperature of 27 °C, 80% relative humidity, semi-tropical climate and average temperature of 23 °C[1]. Agriculture is the main source of income in the province, with orange (*Citrus sinensis*) being one of the main crops in this area[2,3] along with coffee, pineapple and other fruits. Orange is a non-climacteric fruit, so it should be harvested in a timely manner to avoid having effects on organoleptic quality during postharvest handling.

Peru comprises 1% of the world market in citrus and oranges, although it has had a remarkable growth during the last decade[4]. Junín, whose main orange production block is located in the Central Jungle, ranks first in production volume in the country with 11,302 ha of sowing and 15.70 MT/ha. Most of the fruit is destined for the local market. The main international sales markets are the United Kingdom, the United States, and the Netherlands[5].

Moreira and Intriago[6] determined a 5.18% loss of oranges in Ecuador, considering the detachment of the fruit and transport to the collection center. Miranda *et al.*[7] mentioned that the harvest costs involved in the orange production chain correspond to 44% of the total value in Brazil, while mechanical damage decisively affects the quality of oranges. In contrast, orange losses during the planting and marketing process in Peru are unknown, as well as their direct influence on the rural economy.

It has been observed that, during the orange postharvest process, there are generally physical and economic losses. Physical losses include detachment, reception and sorting operations[6], while economic losses are due to unforeseen costs in the production chain. Also considered are losses per season, in stockpiles, by method of transport and during transportation[8]. In order to reduce the impact of the problem, the use of coating agents[9], optimization of planting techniques or improvements in transport and trade techniques[10,11], among others, have been proposed.

Considering the above, there is a need to determine the economic impact of postharvest losses of *Citrus sinensis* produced in the province of Satipo. The objectives of this study were to establish the causes of postharvest losses of *Citrus sinensis*, to determine the stage at which the greatest losses occur, and to determine the economic value inherent in postharvest losses.

2. Materials and methods

The research was of an applied type, the research level was descriptive and the specific method was inductive-deductive.

2.1 Experimental design

The methodological design included direct observation, counting and evaluation of physical damage to oranges from each tree sampled. In the case of intermediaries and traders, surveys and interviews were applied.

The population consisted of all the orange plants in the Rio Negro zone, within the province of Satipo, which is focused on citrus production. Ten trees were selected from each plot in the zone. Sampling considered canopy volume, fruit production, height and location within the plot.

The trees sampled were isolated perimetrically of approximately 20 m^2. In the sampled areas there is no grazing or access of livestock, so the initial minimum source of loss was due to the action of birds, insects and the effect of climate, similar to that described for the high forest of Cusco[12].

The intermediaries were selected based on the volume of product transported and the average distance they traveled. Three randomly selected intermediaries were considered with an average distance of 436 km (distance between Satipo and Lima, the market with the highest volume of orange consumption in Peru). In the case of retail traders, 5 destination traders were randomly selected from the intermediaries whose purchase volume was greater than 1,000 units of the fruit.

2.2 Materials

The materials used for the research were: a titration equipment, potentiometer, brixometer and other resources for data recording. In addition, an observation guide and questionnaires were used for producers (questionnaire 1), intermediaries (questionnaire 2) and retailers (questionnaire 3).

The validation of the questionnaire was carried out by expert judgment. The validity coefficient obtained for questionnaire 1 was 0.89, questionnaire 2 was 0.88 and questionnaire 3 was 0.88. The average Cronbach's Alpha coefficient obtained for the three was 0.58, which represented a moderate confidence.

2.3 Experimental procedure

The general process from harvest to trade of the orange is described in **Figure 1**, based on Hussein *et al.*[11], Martinez-Romero *et al.*[13] and Malik *et al.*[14]. Considering the experimental design, the loss of *C. sinensis* was evaluated at each macro-stage of the process: harvest, intermediate and trade. In the case of large volumes of fruit transported (tens of thousands per harvest season), the usual approximate quantities provided through questionnaires applied to intermediaries and sellers were used.

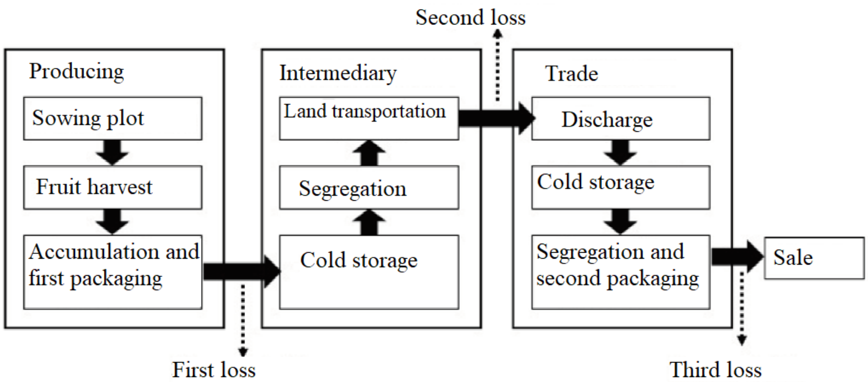

Figure 1. Production chain for orange sales. The highest volume postharvest losses are shown for the three main macro-stages: producer, intermediary and trade.

Ten ripe oranges corresponding to each plot were collected and the corresponding °Brix, pH and acidity were determined at the Bromatology Laboratory of the Faculty of Agricultural Sciences of the UNCP. This was done with the objective of determining the existence of notable differences in the product in each sampled area.

Surveys were then applied to each participant in the production chain, with the objective of determining the approximate number of oranges that were marketed in the sampling periods and the total losses in the same time interval: August 2018 (dry season) and December 2018 (rainy season).

The statistical parameters considered were mean, standard deviation and percentage analysis and were processed in spreadsheets.

3. Results and discussion

3.1 Laboratory analysis of orange samples

The results of the analysis of °Brix, pH and acidity are shown in **Table 1**. The overall average obtained were 9.50 ± 1.58 °brix, 3.44 ± 0.26 pH and 1.39 ± 0.32 acidity, these values are within the parameters of the Peruvian Technical Standards NTP 011.023.2014 and other similar studies[15–17]. The results do not show significant deviations ($p < 0.05$) among them and neither is a pattern observed in the variables analyzed. Since the distribution of the characteristics is random, an effective characteristic of the same product that caused its loss during the transport and trade chain is not distinguished.

Table 1. Results of °Brix pH and acidity analysis in harvested oranges

Number of samples	°Brix	pH	Acidity
Sample 1	9	3.11	1.04
Sample 2	11	3.24	1.13
Sample 3	11	3.15	0.99
Sample 4	8	3.52	1.86
Sample 5	10	3.65	1.73
Sample 6	12	3.49	1.66
Sample 7	7	3.21	1.58
Sample 8	8	3.84	1.22
Sample 9	9	3.76	1.16
Sample 10	10	3.44	1.55
Average (±d.e.)	9.50 (±1.58)	3.44 (±0.26)	1.39 (±0.32)

Likewise, no significant differences were observed in the color or thickness of the orange peels, with a rough rind with a regular thickness of 5 mm. The differences between all the samples lie in the solute content of the fruit juice, whose origin lies in the particular treatment that each plot has received, soil quality and available nutrients[18]. Subsequent chemical, mechanical and biological damage affects the initial quality of the fruit, so it is not possible to conserve fruit quality for prolonged periods.

3.2 Effect of season during harvest

Growers were interviewed and *C. sinensis* crop yields were evaluated during two different seasons August 2018 (dry seasons) and December 2018 (rainy season). The loss results for each plot studied are shown in **Table 2**. The results indicate higher harvest in the month of August, as well as a higher proportional amount of loss relative to the month of December.

This is mainly due to the fact that the peak harvest season for the fruit in the region occurs during the summer season, after fruit growth in June and July.

Additionally, the higher production volume and lower storage conditions and capacity could influence on crop yield due to the absence of capacity in storage, transportation and marketing[10,19]. The capacity of producers and intermediaries could have been affected by the absence of means to control insects, fungi and mechanical damage[11].

Table 2. Orange losses in two harvesting periods

Location	August 2018			December 2018		
	Harvest	**Loss**	**%**	**Harvest**	**Loss**	**%**
Plot 1	30,000	453	1.51	10,000	254	2.54
Plot 2	21,000	705	3.36	7,000	168	2.40
Plot 3	28,000	550	1.96	9,000	413	4.58
Plot 4	40,500	874	2.16	13,000	147	1.13
Plot 5	50,000	1,475	2.95	20,000	273	1.37
Plot 6	38,000	644	1.69	15,000	112	0.75
Plot 7	23,000	2,662	11.57	9,700	190	1.96
Plot 8	80,000	1,986	2.48	34,000	271	0.80
Plot 9	55,000	1,387	2.52	21,000	298	1.42
Plot 10	46,000	930	2.02	16,000	389	2.43
Total	411,500	11,666	-	154,700	2,515	-
Average	41,150.00 (±17,782.72)	1,166.60 (±712.47)	3,22 (±2,99)	15,470.00 (±8,013.05)	251.50 (± 99.51)	1.94 (±1.14)

The great variability in the results comes from the different capacity and management of producers, as well as the location and procedures followed during fruit growth. These characteristics and damages are developed in more detail in the loss analysis for each step within the production chain and the final economic evaluation.

3.3 Losses in the harvesting and stripping operation

During the harvesting stage and the detaching operation, there was an average loss of 1.50 (±0.32)% (**Table 3**) in the randomly analyzed tree samples corresponding to each plot. The number of oranges corresponded to the total number of fruits recorded during the harvest seasons in August and December. In all cases, no significant difference ($p < 0.05$) was observed between the different losses for each tree sampled, in none was the presence of pests or other external factors that notably affected the individual yield of the plots. Therefore, the main factors that originated loss were the harvesting operations and first storage of fruit in harvesting bags.

Harvesting is the first line of anthropogenic loss and is carried out by manual detachment from the tree, mechanical harvesting with a device and harvesting from the ground after falling[7]. The standards required for the determination of fruit maturity corresponded to external characteristics (color, shape, shell firmness, texture and presence of spots), organoleptic characteristics (flavor and odor) and those determined by chemical analysis, such as acidity, presence of soluble solids or other chemical components[14].

Table 3. Losses of orange per tree in the peeling operation

Number of trees	Number of oranges per tree	Orange losses per tree	Percentage (%)
Tree 1	715	8	1.12
Tree 2	601	10	1.66
Tree 3	776	9	1.16
Tree 4	708	14	1.98
Tree 5	687	11	1.60
Tree 6	611	8	1.31
Tree 7	753	15	1.99
Tree 8	632	10	1.58
Tree 9	699	9	1.23
Tree 10	684	9	1.32
Total	6,866	103	-
Averages	686.6 (±57.59)	10.3 (±2.40)	1.50 (±0.32)

In the case of harvest, the main damages recorded were cuts, dents, crushing, immaturity, fungal or insect infestation, shell breaks, internal damage due to falling, bird punctures, among others. These damages are frequent during harvest and have been reported by Hussein *et al.*[11], Bhattarai *et al.*[20] and Malik *et al.*[14] for citrus and other tree fruits.

In principle, the poor harvesting procedure and the first storage in bags produced fisiological, metabolic and organoleptic alterations in all fruits. In the case of the fruits analyzed, mechanical damage could affect the soluble solids content, acidity, nutrient content and favor respiratory activity and even generate subsequent color, odor and texture changes[18,21].

3.4 Losses in the transportation operation

The transport operation comprises two moments in the production chain: from the harvest field to the first collection center and from the collection center to the traders or buyers. The results of losses of the oranges identified in the transport operation were 1.75 (±0.18)% as expressed in **Table 4**. The losses recorded are slightly higher than those recorded during harvesting and detachment.

Table 4. Losses of orange per tree in the transport operation

Number of trees	Number of oranges per tree	Loss of fruit	Percentage (%)
Tree 1	715	15	2.10
Tree 2	601	10	1.66
Tree 3	776	13	1.68
Tree 4	708	11	1.55
Tree 5	687	11	1.60
Tree 6	611	10	1.64
Tree 7	753	14	1.86
Tree 8	632	12	1.90
Tree 9	699	11	1.57
Tree 10	684	13	1.90
Total	686	120	-
Average	686,60 (± 57,59)	12.00 (±1.70)	1.75 (±0.18)

The main damages recorded during transport were of the mechanical type, such as cuts, impacts, compressions and shaking[20]. In addition to these, there was also damage due to heat, humidity, light and contact with the juice of other damaged oranges. These damages are usual for this *C. sinensis* and other citrus[8,21].

The transfer operation begins with the first packing in the harvesting sacks, baskets or loading areas of trucks, vans and other means. For farmers and intermediaries in the Central Forest, in this first instance there is no inclusion of a means of cold preservation, so transport and trade should not take too long, with logistics being relevant during this process[22].

The use of natural fibers, metal paper or plastic in the first packaging used during transport causes mechanical damage to the fruit. For this reason, there is a tendency to use soft surfaces or those without much hardness during transport, in addition to considering their shape and size[13,21]. The absence of these means during transport to the collection center could significantly increase the losses found. In addition, the absence of a cold storage medium during transport also had a significant impact on fruit quality, shelf life and nutritional content[11,21,23].

In addition to packaging, other factors that increase losses are failures attributed to the method of transport (mechanical failures, age or accidents), distribution of contents in packaging and cargo, incorrect transport management, inadequate handling techniques, absence of load chains and organization, poor loading, transport and unloading procedures, and the state of the roads[24]. Added to these is the lack of experience and commitment of drivers.

The impact of poor transportation techniques is relatively frequent in the Junín region of Peru. In 2018, 2,287 traffic accidents were recorded in the region, of which 476 involved skidding, rollovers or both[25] in which a considerable section involved trucks and trailers dedicated to food transportation.

3.5 Losses in storage and transportation due to intermediaries

The storage process is crucial within the production chain due to its importance in the conservation of *C. sinensis*[11,14], especially due to its high water and sugar content, which are media for the cultivation and development of bacteria and other pathogens[23], as well as favoring cellular respiration and weight loss[13].

In the central jungle of Junín, intermediaries buy oranges from the plots to sell them to markets in the capital Lima. **Table 5** shows the approximate losses described by three intermediaries in the area with a collection volume of more than 50,000 units. A loss of 4,900 units of oranges out of 220,000 in total was found, equivalent to 2.23 (±0.81)%, higher than the harvest and first transport.

Table 5. Losses of Citrus sinensis in transport and storage due to intermediaries

Number of intermediaries	Number of oranges purchased	Losses	Percentage (%)
Intermediary 1	50,000	1,000	2.00
Intermediary 2	80,000	2,500	3,13
Intermediary 3	90,000	1,400	1,55
Total	220,000	4,900	-
Average	73,333.33 (±20,816.66)	4,900 (±1,633.33)	2.23 (±0.81)

A process prior to storage is the washing of the fruits with detergent or soap, in order to remove solid residues, pesticides, animal feces, soil and dust to which they were exposed during their development.

Fermentative processes in citrus are relatively faster than in other fruits so two procedures are chosen during citrus storage: (1) prevent the growth of fungal colonies, bacteria, insects and diseases such as HLB, produced by the bacterium *Candidatus Liberibacter*, by creating a favorable storage environment[26], or (2) prevent the colonization of these harmful elements by limiting their access to the fruits[23]. For (1), optimal storage conditions for *C. sinensis* require a temperature of 4–8 ℃, relative humidity of 90–95%, low concentration of O_2(3–6%) and CO_2 (2.5–4%) for prolonged storage periods[14] and are used for export. The fluctuations or constant changes in these storage conditions harm the fruit and reduce their half-life[8]. However, these require technology that is not available to intermediaries in the Central Rainforest, so conservation during storage focuses on procedure (2) by keeping the fruit in closed and innocuous chambers for the shortest possible time.

For intermediaries residing in the Junín region, the fundamental causes of *C. sinensis* loss in storage are the South American fruit fly (*Anastrepa Fraterculus Wiedeman*), which is quite common in Peru and other regions of the world[8], the insect *Diaphorina citri* vector of HLB[26] and fungi of the genus Penicillium[20]. The frequency of these problems have manifested in considerable farmer and intermediate populations, with variable losses between 10–40% of total yield in dismal conditions[8,20] and in seasons of higher humidity from August to November[14].

The priority protection techniques that occur under these conditions are the application of glutathionic insecticides, fumigation, control of storage temperature (cooling-increase), covering with paper, cardboard or wax, reduction of ambient humidity and even application of organic synthetic preservatives[11,14].

The cellular degradation, product of consumption and cytolysis at the fruit level is the one that finalmente determines the putrefaction of food. In the case of *C. sinensis*, the loss of tissue turgor and firmness due to the breakdown of plant cell walls after harvest is a constant and unstoppable process[11]. Storage time plays an important role here, as it determines the overall crop yield, selling price, and volume purchased by buyers. Oranges harvested in the central jungle, due to environmental conditions and transfer cannot take more than 15 days to the consumer.

3.6 Losses at the retail level

C. sinensis were purchased from middlemen and producers by retail traders. In the case of the present study, 5 traders of that citrus fruit with purchase volumes above 1,000 units were considered. The losses determined reached an average of 2.90 (±1.50)%, as shown in **Table 6**.

Table 6. Orange losses in the market

Merchants	Buy	Losses	Percentage (%)
Merchant 1	2,000	104	5.20
Merchant 2	3,000	55	1.83
Merchant 3	5,000	183	3.66
Merchant 4	1,000	21	2.10
Merchant 5	3,600	62	1.72
Total	14,600	425	-
Average	2,920 (±1,527.09)	85.00 (± 62.23)	2.90 (±1.50)

Losses at trade level have a higher frequency and greater variability than those from harvesting, storage or transport because their period of existence is short and depends on different conditions, often outside of preservation and quality controls.

Although there are not enough studies on the loss of *C. sinensis* during the sales process, research related to the general loss and disposal of food during this stage is being considered. Peru, as part of undeveloped countries, produces 7% of losses during distribution and marketing, of which 44% corresponds to fruits and vegetables, including oranges[27].

The major causes of loss at the trader level were due to poor traceability during the production chain: moldiness, loss of turgidity, mechanical damage, dents, cuts, solid residues and crushing. Poor product characteristics limit product acquisition and reduce the likelihood of future sales[28].

3.7 Evaluation of physical and economic losses during the production chain

Figure 2 shows the scheme of orange losses throughout the production chain up to the point of consumption with an assumed sample of 10,000 units considering the losses indicated above. The overall yield up to the minimum consumer quality disposition was 9,188 units and an accumulated loss of 8.12% of total production.

The results indicate that the greatest losses occur in the storage and consumer sale stages due to the prolonged period of exposure to environmental conditions and the precarious conservation procedures of the fruit during postharvest. This causes the attack of insects, fungi and bacteria that reduce the quality of the food, preventing its consumption by the public. It should also be considered that quantities may vary depending on production volumes, since the smaller the quantity harvested and traded, the greater the susceptibility to loss[11].

In the experimental design, the survey has been used as an instrument and the initial stockpile volumes belong to approximate quantities, so the actual final yield may be higher than the one described in the experiment.

In the central jungle of Peru, the market provides the cost per unit of orange at US$0.017, so that during the production chain (10,000 units of

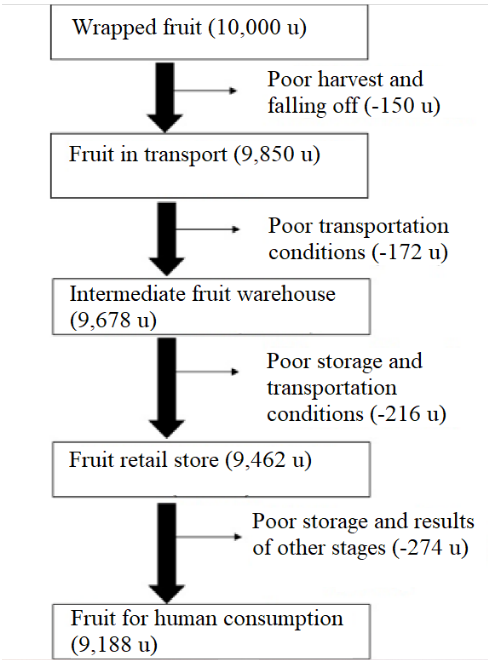

Figure 2. Overall yield and unit loss of *C. sinensis*.

fruit available), with a cost of US$170, there is an overall loss of US$13.80. Although the quantity is significantly lower, the general accumulated of the rest of the producers in the area and the uncertainty corresponding to the method provide a significant loss perspective.

Flores *et al*.[29] postulates an approximate orange mass of 240 g per unit, so the mass extrapolation indicates a loss of US$5.75 per ton of *C. sinensis* produced and traded in the local market. These results are lower than those determined by Bhattarai *et al*.[20] with a loss of 41% and Musasa *et al*.[8] of 40% per farm studied in Africa. In Peru, there are no studies that have studied the overall production yield of these citrus fruits and have stuck to the local conditions of the Central Rainforest.

4. Conclusions

The causes of postharvest loss of orange *Citrus sinensis* in the central jungle of the Junín region of Peru were evaluated through the evaluation of fruit quality and percentage evaluation of losses at each stage of the production chain. It was determined that there were no differences between the fruits of the sampled plots (average of 9.50 °Brix, pH of 3.44 and acidity of 1.39) and the highest volumes of harvest losses occurred in the dry season (August 2018). For each stage of the production chain, average losses were determined to be 1.50% in harvesting and detaching, 1.75% in transport to the collection center, 2.23% in storage and transport by intermediaries and 2.90% in storage and sale by retailers. The main causes were poor harvesting procedures, poor storage conditions and careless means of transport. The main damages observed were mechanical (cuts, dents and compressions) and biological (fungi, bacterial attack and fruit flies). The total loss in the entire chain is 8.12%, and for each MT of fruit harvested in the region, there is a loss of US$5.75 from harvest to sale to the consumer.

Conflict of interest

The authors declare no conflict of interest.

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