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Strategies for reducing the waste of fruit and vegetable supply chains: the search for sustainable wholesale systems

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ABSTRACT

The expanding demand for food is driven by population and economic growth. One strategy to meet this expansion of demand and reduce pressure on food production is to minimize food waste. This study aims to evaluate whether the combination of operational and management practices in the fruits and vegetables logistics and commercialization stages are associated with lower levels of wasting in the wholesale sector. Five products from the fruits and vegetables group were analyzed: lettuce, potatoes, oranges, papayas, and tomatoes, sold by wholesalers at a Wholesale Food Market (CEASA). Principal component analysis and association rules were used to recognize the interrelationship of practices that promote the reduction of waste. The self-reported waste of papaya and potato is 5.8%, for lettuce 22.5%, tomato 3.3% and orange 2.2%. There are thirteen practices and behaviors that explain 100% of the variance, which are composed by a technological component and a marketing component. Based on the association rules, the high frequency of eight practices, such as the provision of customer support services and the use of cold chambers, correlate to the reduction of fruits and vegetables waste.

Keywords: Agri-food chain, food loss and waste, post-harvest techniques.

RESUMO

Estratégias para reduzir o desperdício de frutas e hortaliças: a busca por sistemas atacadistas sustentáveis

A crescente demanda por alimentos é impulsionada pelo crescimento populacional e econômico. Uma estratégia para atender a essa expansão da demanda e reduzir a pressão sobre a produção de alimentos é minimizar o desperdício de alimentos. O objetivo deste trabalho é avaliar se a combinação de práticas operacionais e gerenciais nas etapas da logística e comercialização de frutas e vegetais estão associadas aos menores níveis de desperdício no setor atacadista. Foram analisados cinco produtos do grupo de frutas e hortaliças: alface, batata, laranja, mamão e tomate, vendidos por atacadistas da Central de Abastecimento de Alimentos (CEASA). Foram utilizadas a análise de componentes principais e as regras de associação para reconhecer a inter-relação das práticas que promovem a redução de desperdícios. O desperdício autorreferido de mamão e batata foi de 5,8%, para alface 22,5%, tomate 3,3% e laranja 2,2%. Foram identificadas treze práticas e comportamentos que explicam 100% da variância, e que estão associadas ao componente tecnológico e ao componente de comercialização. Com base nas regras da associação, a elevada frequência de oito práticas, como a prestação de serviços de apoio ao cliente e a utilização de câmaras frigoríficas, está relacionada com a redução do desperdício de frutas e vegetais.

Palavras-chave: Cadeia agroalimentar, perda de alimentos e desperdício, técnicas pós-colheita.

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Worldwide population growth has significantly increased food consumption, which in turn has increased demand for food production and distribution (Bloemhof & Soysal, 2016). Consumers have become more demanding regarding the attributes of quality, diversity, integrity, safety, sustainability and information services associated with food and food products. Managers of the food and agribusiness industry will have to respond to these changes in consumer demands by increasing the sustainability of processes and products (Wognum *et al*., 2011).

Food waste in the fruit and vegetable chains in developed countries is higher in the stages of agricultural production, being 20% of waste at harvest, 8% in transport and 15% in processing (FAO, 2011) and distribution (Plazzotta *et al*., 2017). In retail, food waste worldwide is about 15% on average, but it can be higher in developing countries, for instance, it can reach 35% in sub-Saharan Africa regions (FAO, 2019). During storage stages, inadequate infrastructure, refrigeration and inefficient management contribute to increased waste, specially in developing countries (Laurentiis *et al*., 2018).

The Food losses and waste (FLW) that occur in food supply chains and in

final consumption is due to the behavior of retailers and consumers. Food waste contributes to food insecurity, especially in developing countries (FAO, 2019).

Despite the modernization of production systems and the fruit and vegetable logistics chain, food wastes are recurrent and difficult to measure (Magro & Talamini, 2019; Henz, 2017). According to Lima & Oliveira (2021), wholesale markets losses were classified in the distribution and sale of fruits and vegetables in five dimensions: logistics, operations, technology, trade and management.

In Brazil, the dynamics of supply and marketing in wholesale markets have characteristics of public-private regulation, with different realities of management, infrastructure and technology (Belik, 2018). These differences impact not only the marketing and distribution of products, but also the value chain upstream and downstream, which can contribute not only to a greater supply and availability of food, but also to lower levels of losses and food waste (FAO, 2019).

This Brazilian case study explores this gap and proposes efficient procedures to mitigate food waste, focusing on wholesale. This study aims to evaluate whether the combination of operational and management practices in the fruits and vegetables logistics and commercialization stages are associated with lower levels of wasting in the wholesale sector. This research contributes to the proposition of strategies that allow the establishment of fruit and vegetables sustainable supply chains identifying different ways to reduce food waste.

MATERIAL AND METHODS

Data description

From the definitions of food loss and food wastes (Bendinelli *et al.*, 2020; Gao *et al.*, 2021), intentional losses are associated with the initial stages of the food supply chain, from agricultural production to agro-industrial processing (Figure 1), while intentional waste is associated with those occurring from the wholesale market to the consumer market (Figure 1). The research focused on the wholesale market in one of the main Wholesale Food Markets in Brazil, CEASA Campinas (Figure 1). Fresh foods of different perishability characteristics were evaluated, i.e.: lettuce (*Lactuca sativa*), potato (*Solanum tuberosum*), orange (*Citrus sinensis*), papaya (*Carica papaya*) and tomato (*Lycopersicon esculentum*). These are among the most consumed and commercialized fruits and vegetables (FV) by the Brazilian population, according to the latest Family Budget Survey (in portuguese Pesquisa de Orçamentos Familiares), POF 2017-2018 (IBGE, 2019).

The survey evaluated the transport of products to CEASA Campinas and the storage, processing and marketing operations. The focus of this study is high-lighted in dotted lines in Figure 1.

The Wholesale Centers (named CEASAs) are responsible for the largest volumes of fruit and vegetables sold in Brazil (CONAB, 2020). The CEASAs form a decentralized network, with 69 units. CEASAs are the main suppliers of food to the Brazilian urban population. CEASA Campinas is an important fruits and vegetables commercialization center and other fresh products for the state of São Paulo, being responsible for supplying more than 500 municipalities. There are more than 580 wholesalers, distributed in about 940 stores (CEASA, 2021). The boundary of the study is the Campinas Wholesale Food Market (Figure 1) and it was chosen due to: (i) easy access and collection of information from the traders; (ii) in the 2017-2019 three-year period, 1.8 million tons of food were sold, of these, 560 thousand tons of fruits and vegetables, ranking as the eighth largest wholesale central in the country (CONAB, 2020); (iii) products that are not sold are destined to the Solidarity Institute for Food Programs (ISA). The Institute is a non-governmental organization that works within CEASA Campinas. ISA emerged with the objective of combating hunger and waste, ensuring the use of surplus fruits and vegetables to encourage donations from CEASA Campinas wholesale merchants.

The number of wholesalers that sell exclusively lettuce, potato, orange, papaya and tomato totals 81 wholesalers. 79 wholesalers from CEASA Campinas agreed to participate in the survey (response rate of 97.5%) and wholesalers were encouraged and sensitized to participate through CEASA Campinas managers (President, technical directors, managers and market technicians) who supported this survey. In addition, the Association of Wholesalers of CEASA Campinas (Assoceasa) reinforced the importance of research and the participation of merchants in responding truthfully. The sample universe consisted of 11 wholesalers of lettuce, 15 of potato, 11 of orange, 19 of papaya and 23 of tomato. To maintain the wholesalers' anonymity, they were coded with sequential numbers from 1 to 79. The products were chosen based on their representative share by marketed weight in each of their groups and the value of the reference price, which is obtained by the product between the available quantity expressed in kg and the average price expressed in R$/kg. The result is a reference value in R$ that represents the economic contribution of fresh products entering the market. The available value is obtained from the purchase invoices for products that enter CEASA and prices are recorded by the Horticulture Department at each street fair (CEASA, 2021) and a semi-structured questionnaire with 17 questions (Box 1) answered by the 79 respondents and the database has 1,343 instances.

The producers were grouped into two segments: high and low levels of waste. When the self-declared value of waste was above the average value (obtained by the arithmetic average of all values reported by wholesale merchants) of waste for each product, a high level of waste was considered, otherwise, a low level of waste was considered.

Applied methods and techniques

In order to classify the levels of waste based on operational and management practices during the logistics of distribution and marketing of fresh horticultural products, in the

first set of analyzes, PCA was applied. In the second set of analyzes, a data mining technique, consisting of the search for non-obvious association rules, was used to identify which combinations of variables promote low food loss rates.

PCA is an efficient technique for transforming a set of correlated variables into a smaller set of uncorrelated variables, projecting them into a substantially smaller new plan, increasing their interpretability and minimizing information loss (Jollife & Cadima, 2016). Association rules are part of data mining techniques that seek to identify non-obvious patterns that represent patterns of relationship between varibles in a database (Agrawal *et al.*, 1993).

The set of information used in the data analysis, produced a matrix $n \times k = (79 \times 17)$, where n is the number of wholesale traders interviewed and k is the number of variables evaluated in the distribution and marketing logistics chain of the evaluated products (Box 1).

The total variability contained in the original variables can be expressed as the total variability contained in the PCs. The contribution of each PC (Z_i) is expressed as a percentage, and the individual contribution of each PC can be calculated, for example, for the k-th PC as:

$$C_k = \frac{Var\,(Z_i)}{\sum_{i=1}^{p} Var\,(Z_i)} * 100$$

The Apriori algorithm is an iterative algorithm that performs two activities. The first is the generation of candidates from a set of frequent *k - itemset* that come from the previous iteration. The second activity is scanning the database *D* for the count of candidates for each transaction. In the *kth - iteration*, candidates *k - itemset* in *CK* (set of candidates *k*) are generated from frequent itemsets from the previous iteration (*k - 1*) that constitute *Lk - 1* (set of frequent *k*). Subsequently, the *k - itemset* subsets of each transaction *t* are compared with the candidates in *Ck* for counting the support. *Ck* is obtained by conditionally joining *Lk - 1* and eliminating sets of items that do not satisfy the Apriori property. According to this property, all *Ck* itemsets can be removed from *Ck* if any of its (*k - 1*) - *itemset* are not present in *Lk - 1* (Agrawal & Srikant, 1994). The rule support is the fraction of the number of transactions that contain $X \cup Y$ in *D*, that is, it is the minimum number of occurrences. Trust is the fraction of the number of transactions containing X that also contains Y, therefore it is the percentage of transactions that satisfy X and Y.

It is for this contribution of the total variance, that the model of k principal components is responsible, and in this way, it is possible to determine the number of PCs that must be retained and, in general, the PC with the greatest variance is chosen as the first principal component.

The second set of analyzes was carried out through the discovery of association rules using the Apriori algorithm. The purpose of applying the association rules methodology is to find all relevant rules among the variables under analysis. In general, we have: *X (antecedent)→Y (consequent)*, in a database of transactions t.

The process of extracting association rules was initially presented in Agrawal *et al.* (1993) as a technique that finds relationships between the occurrence of items in transactions in a database. Let $I = \{i_1, i_2, ..., i_n\}$ be a set of literals, called items. An $X \subseteq I$ set is called an itemset. An *X* itemset with *K - elements* is called a *K - itemset*. Let *D* be a database with transactions t that involve elements that are subsets of I. The transaction t supports an itemset *X* if $X \subseteq t$. An association rule is an expression of the form $X \rightarrow Y$, where *X* and *Y* are itemsets.

The rule support is the fraction of the number of transactions that contains $X \cup Y$ in *D*, that is, it is the minimum number of occurrences. Trust is the fraction of the number of transactions containing *X* that also contains *Y*, therefore it is the percentage of transactions that satisfy *X* and *Y* (Agrawal *et al.*, 1993; Singh *et al.*, 2018). For this study we have 79 instances (respondents) and 17 attributes as *X* and the waste level as *Y*. The minimum support was 0.15, confidence of 0.9 and number of rules equal to 10.

RESULTS AND DISCUSSION

During data collection, the wholesale merchant was asked to report the waste associated with the product. Thus, declared waste is based on the experience of each wholesale merchant for each of the evaluated fruits and vegetables, functioning as a waste estimate during the logistics of trade and distribution.

Seventeen variables related to behaviors and practices were extracted from the questionnaire, which, associated with the distribution and commercialization logistics chain, have either a positive (+) or negative (-) relationship with food waste (Table 1).

For all evaluated products, the highest average of the waste declared by the wholesalers is associated with the lowest number of actions related to the prevention practices. Potatoes presented the lowest number of practices by wholesalers associated with less waste (Table 1).

For low waste and all products, the highest average for declared waste was observed when the greatest number of practices related to waste prevention were performed. Tomatoes and papayas had the highest number of practices, with 109 and 106 shares, respectively (Table 1).

When considering the contributions of 17 variables for papaya, potato, lettuce, orange and tomato, two components were extracted (Figure 2) and they account for 100% of the total variance in the data. The first and second components contributed to the variance 68.92% and 31.32%, respectively.

The first component generated is formed by the variables: markets in-packaging products, has a cold chamber, has quality control of purchased products, provides packaging, buys products according to opportunities, has handling operation in marketing, provide utility for non-marketed products and practice transshipment. As they are variables associated with technological and operational issues of commercialization, this component 1 was called technological component. The second component generated is composed of the variables: type of

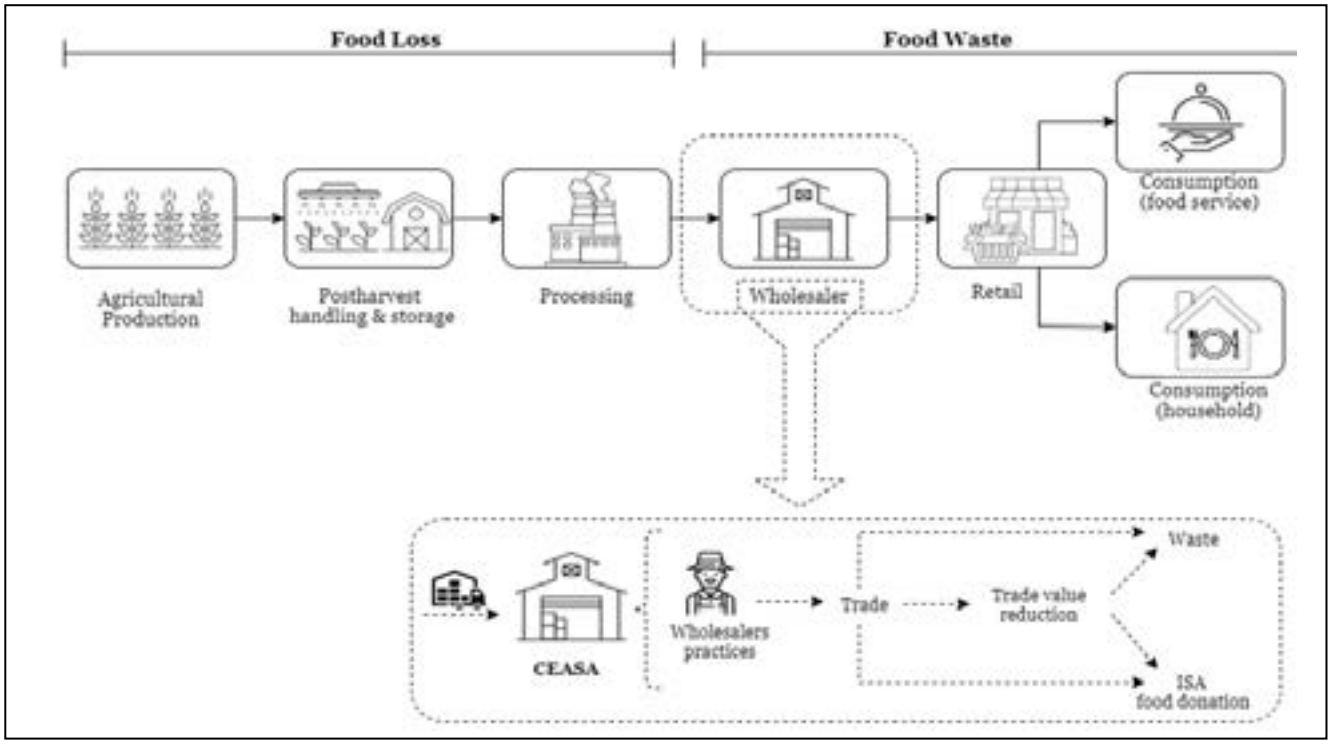

Figure 1. Losses and waste associated with the food supply chain. Campinas, CEASA, 2018/2019.

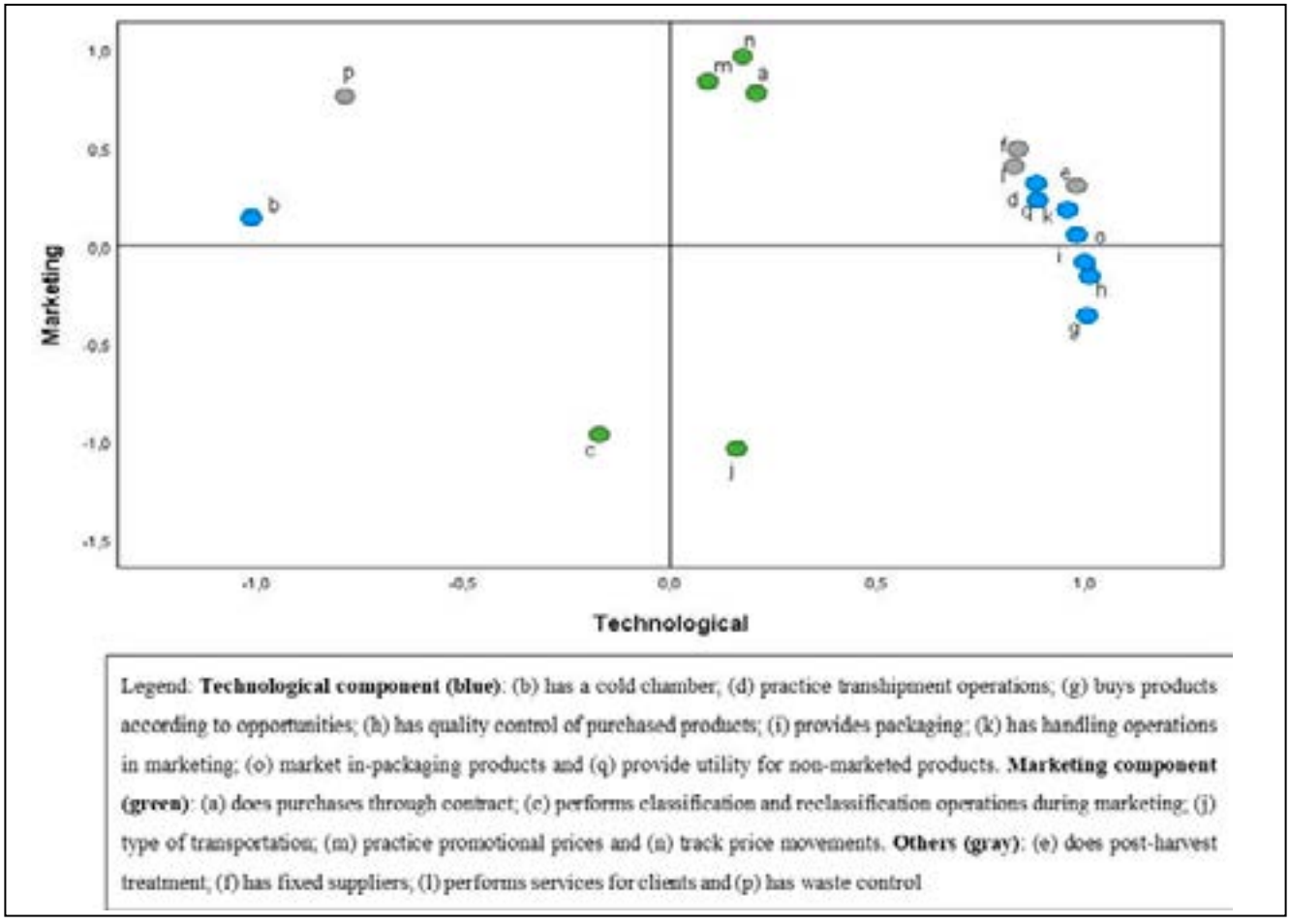

Figure 2. Contribution of variables to the technological and marketing components. Campinas, UNICAMP, 2019.

Box 1. Description of variables collected from CEASA-Campinas wholesale merchants and used for analysis. Campinas, UNICAMP, 2019.

Variable	Nomenclature	Description
Has handling operations in marketing	Handop	Identify if any handling operation is performed during sales.
Practice transhipment operations	Transhop	Identify whether there are transhipment operations.
Market in-packaging products	Marketprod	Identify whether there is use of packaging in the sales of products.
Has quality control of purchased products	Qualcont	Identify if procedures are carried out to assess the quality status of the purchased products.
Provides packaging	Propack	Identify whether there is a supply of packaging suitable for the type of product sold to the producer or the buyer.
Performs classification and reclassification operations during marketing	Classreclass	Identify if there are product classification and/or reclassification procedures, according to the maturity status of the products.
Has a cold chamber	Coldch	Identify the use of a cold chamber.
Does post-harvest treatment	Posttreat	Identify if there are post-harvest treatment procedures, such as treatment with wax, application of fungicides, drying, among others.
Type of transportation	Typetransp	Identify the type of transport that the wholesaler uses to transport his products.
Performs services for clients	Servclients	Identify if there is provision of services to the customer (consignment of products, exhibitors).
Practice promotional prices	Promoprices	Identify whether promotional pricing is practiced.
Track price movements	Pricemov	Identify whether the wholesaler follows price movements of other merchants who sell the same products.
Does purchases through contract	Purccontract	Identify how the wholesale merchant's product sale occurs, such as whether there is a contract or contractual requirement
Buys products according to opportunities	Buyopp	Identify if there is an opportunity purchase by the wholesaler. If the merchant buys a product from a supplier who has no commercial relationship.
Provide utility for non-marketed products	Utilitprod	Identify if there is a directing of products not sold to another destination, such as, for example, food bank, social assistance institutions, among others and not for garbage.
Has waste control	Wastecon	Identify whether there is waste control of products during marketing.
Has fixed suppliers	Fixedsup	Identify whether the products sold are supplied by producers or fixed suppliers.

transportation, performs classification and reclassification operations during marketing, practices promotional prices, tracks price movements and does purchases through contract. These variables are associated with marketing logistics, so component 2 was called marketing component.

These two components contributed to 100% of the variance, so the other variables are not mentioned as they do not contribute to the two components, but are shown in Figure 2. The analysis from data mining using the Apriori association methodology, showed that the combination of certain practices is responsible for low waste of the analyzed vegetables. Among the ten rules extracted from the model, nine rules indicate the practice by wholesale merchants that are associated with low waste of products and a rule for not performing practices that are associated with high waste of horticultural products (Box 2). The practices that contribute to greater logistics chain efficiency are: monitoring price movement, use of cold chain with regards to transport and storage, and the provision of services in accordance with the specificity of the customer. These were the variables associated with low levels of waste.

Countries that have been reducing food waste rates have invested in building infrastructure, such as storage facilities, coupled with the transfer of knowledge and technology along the food supply chain (Bendinelli *et al.*, 2020). Strengthening relations between government, industry and rural producers can contribute to reducing post-harvest losses (Gardas *et al.*, 2017).

The frequencies of the variables were identified in the association rules (Box 2) related to low waste. Of the 17 possible practices carried out by the wholesale merchants in the chain, eight of them stood out (Box 2). Three practices are common for all nine rules associated with low waste. The practices perform services for clients, practice promotional price and cold chamber are present in the nine rules with highest confidence index.

The provision of customer support services is related to wholesalers who have a large clientele and is comprised of sales support, consignment of fruits and vegetables and provision of marketing actions such as the dissemination of the product's functional and nutritional properties and tasting at point of sale, among others.

The cold chain is a consolidated practice (Chaudhuri *et al*., 2018) which is associated with greater stability of plants, mainly of fruits, being an efficient technological resource to delay physiological processes associated with plant degradation. Any failure in the cold chain causes irreversible damage to product quality, so temperature monitoring and maintenance are essential to prevent waste.

The practice of promotional prices allows the wholesaler to keep up with market price movements and keep his product commercially attractive, apting it to the new commercial level. This is a widely explored practice to avoid food waste (Lebersorger & Schneider, 2014). Food still safe to be consumed, but not sold, may be destined for social assistance entities. Food at CEASA Campinas, when it can no longer be sold, is sent to ISA.

In the logistics of distribution and marketing of tomatoes, the use of suitable packaging is common practice, carried out by wholesale merchants who adopt plastic boxes and cardboard boxes for tomatoes. Similarly, for oranges polypropylene mesh sacks and cardboard boxes are used. Post-harvest treatment operations in owned or shared packing houses occur regularly for these products.

Lettuce has particular distribution and marketing logistics characteristics that differ considerably from the other products analyzed. Most are small or medium producers, directly responsible for the production and commercialization of their products. Since the lettuce wholesaler is also

Table 1. Practices frequency of wholesale traders for high and low declared waste of papaya, potato, lettuce orange and tomato. Campinas, UNICAMP, 2019.

Variable	Contribution of waste	Number of actions									
		High waste					Low waste				
		Papaya	Potato	Lettuce	Orange	Tomato	Papaya	Potato	Lettuce	Orange	Tomato
Handop	-	6	1	5	2	5	7	3	3	8	12
Transhop	+	5	4	5	2	6	3	0	2	6	2
Marketprod	-	7	7	4	5	10	10	8	6	9	13
Qualcont	-	5	2	5	3	3	10	4	4	9	5
Propack	-	2	0	4	3	9	6	1	4	6	9
Classreclass	-	9	1	4	3	6	8	3	0	9	12
Coldch	-	6	0	3	1	1	10	1	4	6	3
Posttreat	-	6	6	6	4	6	7	8	6	9	10
Typetransp	-	7	0	5	4	6	8	7	5	3	7
Servclients	-	4	3	1	4	6	8	4	4	2	8
Promoprices	-	6	4	6	3	10	10	7	6	8	13
Pricemov	-	8	4	5	4	10	9	7	6	8	13
Purccontract	-	7	3	6	4	5	9	8	5	6	6
Buyopp	+	6	3	3	3	2	4	0	3	8	1
Utilitprod	-	9	5	5	5	10	10	8	6	9	12
Wastecon	-	7	4	4	4	7	10	0	6	6	10
Fixedsup	-	6	2	5	3	7	8	8	6	9	11
Total Practices		106	49	76	57	109	137	77	76	121	147
Average declared waste		8.4	9.8	27.4	3.3	6.5	3.5	2.4	16.6	1.3	0.7

Box 2. Association rules generated from the apriori algorithm for all instances with 0.15 support. Campinas, UNICAMP, 2019.

Rule	Rules description {A,B}→C	Confidence
1	{Does purchases through contract, has a cold chamber, has quality control of purchased products, performs services for clients and practices promotional prices} → Low waste	1.00
2	{Does purchases through contract, has a cold chamber, performs services for clients, practices promotional prices and has waste control} → Low waste	1.00
3	{Does purchases through contract, has a cold chamber, has quality control of purchased products, performs services for clients, practices promotional prices and has waste control} → Low waste	1.00
4	{Has a cold chamber, performs services for clients, practices promotional prices and has waste control} → Low waste	0.93
5	{Has a cold chamber, has quality control of purchased products, performs services for clients and practices promotional prices} → Low waste	0.93
6	{Has a cold chamber, has quality control of purchased products, performs services for clients, practices promotional prices and has waste control} → Low waste	0.93
7	{Has a cold chamber, performs services for clients, practices promotional prices, tracks prices movements and has waste control} → Low waste	0.93
8	{Does not have a cold chamber, does not transhipment operations and does not provide utility for non-marketed products} → Low waste	0.92
9	{Does purchases through contract, has a cold chamber, performs services for clients and practices promotional prices} → Low waste	0.92
10	{Has a cold chamber, has fixed suppliers, performs services for clients, practices promotional prices and has waste control} → Low waste	0.92

the producer, the strategy of these wholesalers to reduce commercial losses is to monitor price movements and, at the end of the marketing period, to practice promotional prices. This price-based discount and promotional policy are well-established (Kotler & Keller, 2012).

The wholesale markets are responsible for approximately 85% of the distribution and commercialization of the total production of table potatoes in the Brazilian market. Potato is a product that is marketed freshly harvested, almost skinless (*in natura*) and washed, which contributes to a shorter shelf life. 90% of sales are made in 50 kg bags and 10% in 25 kg bags, which makes it impossible for the wholesaler to control the quality of products. Potato packaging is still an obstacle to be overcome, as it is very heavy, is harmful to handlers and is associated with frequent product damage (Kaguongo *et al*., 2016).

Wholesale merchants of papaya commercialize the product in type K packaging, although there is a small portion that stores papaya in plastic and cardboard packaging. The purchase of products according to price opportunities is more practiced in this chain than in the others evaluated. The transport takes place in trucks with open and wide bodies, the use of refrigerated or air-conditioned trunk bodies is not adopted, which is the most suitable type of transport for this product. Transport conditions are essential to maintain the good condition of vegetables, the absence of refrigeration contributes to the maturation and early senescence of these products (Santos *et al*., 2020).

There is still potential for reducing food waste as the results show. This study points to efficient practices and behaviors for successful interventions in reducing waste in the vegetable supply chain and can help public managers, retailers and wholesalers to adopt best practices.

Food waste in the fruit and vegetable logistics and distribution chain is multifactorial, with the complex intersection between declared waste and the identified variables or attributes of the analyzed products. The main strategies that should be pursued to mitigate the waste of fruits and vegetables are to improve the promotional pricing policy strategy in function of the dynamics of supply and demand of the products, to use refrigerated transport and cold storage to conserve products and, finally, to provide differentiated services to customers, offering superior quality products.

Public policies and actions involving retailers, wholesalers, distributors and social organizations involved in the distribution and marketing logistics chain at Wholesale Centers can be implemented to mitigate waste.

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