





Thermal condition of mate (*Ilex paraguariensis*) processing

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ABSTRACT: The *Ilex paraguariensis* is a species native to Brazil, Paraguay and Argentine, valued by its positive effects on human health. Mate processing consists of the following stages: pre-drying (rapid drying at high temperature, known as *sapeco* operation), drying, and milling. In order to verify the current process and to propose future improvements to the mate processing, thermal and mass balance analysis were applied to industrial mate processing units. Results showed that the consumption of energy in *sapeco* and drying operations exceeds the calorific input necessary for these operations. These results verify the need for a change in the management of temperatures in the *sapeco* and drying stages of mate processing in order to optimize the consumption of energy, resulting in lower costs, with positive effects on the quality of the mate products.

Key words: mate, *Ilex paraguariensis*, processing, mass balance, temperature.

Análise das condições térmicas do processamento da erva-mate

RESUMO: A *Ilex paraguariensis* é uma espécie nativa do Brasil, Paraguai e Argentina, valorizada por seus efeitos positivos na saúde humana. O processamento do mate consiste nas seguintes etapas: pré-secagem (secagem rápida em alta temperatura, conhecida como operação de sapeco), secagem e moagem. A fim de verificar o atual processo e propor melhorias futuras no processamento de mate, foram aplicadas análises térmicas e de balanço de massa em unidades industriais de processamento de mate. Os resultados mostraram que o consumo de energia nas operações de sapeco e secagem supera o aporte calorífico necessário para essas operações. Esses resultados comprovam a necessidade de uma mudança no gerenciamento das temperaturas nas etapas de sapeco e secagem do processamento da erva-mate, a fim de otimizar o consumo de energia, resultando em menores custos, com efeitos positivos na qualidade dos produtos da erva-mate.

Palavras-chave: mate, *Ilex paraguariensis*, processamento, balanço de massa, temperatura.

INTRODUCTION

Ilex paraguariensis or mate is an arboreal plant and an ombrophile, belonging to the family Aquifoliaceae and the genus *Ilex* (RESENDE et al., 2000; MOLINA & MOLINA, 2004; OMAR, 2009). Today mate, yerba-mate or mate are common names used for the plant, as well as the product comprising exclusively the leaves and stems of *I. paraguariensis*. The production of mate uses management systems of natural and cultivated populations, the main producing and consuming countries being Brazil, Argentina and Paraguay. In Brazil, its cultivation extends through the states of Rio Grande do Sul, Santa Catarina, Paraná and Mato Grosso do Sul. In these states mate occupies a position of considerable social, economic

and cultural importance since it is commercialized by small farmers (VIDOR et al., 2002; ANTONIAZZI et al., 2018).

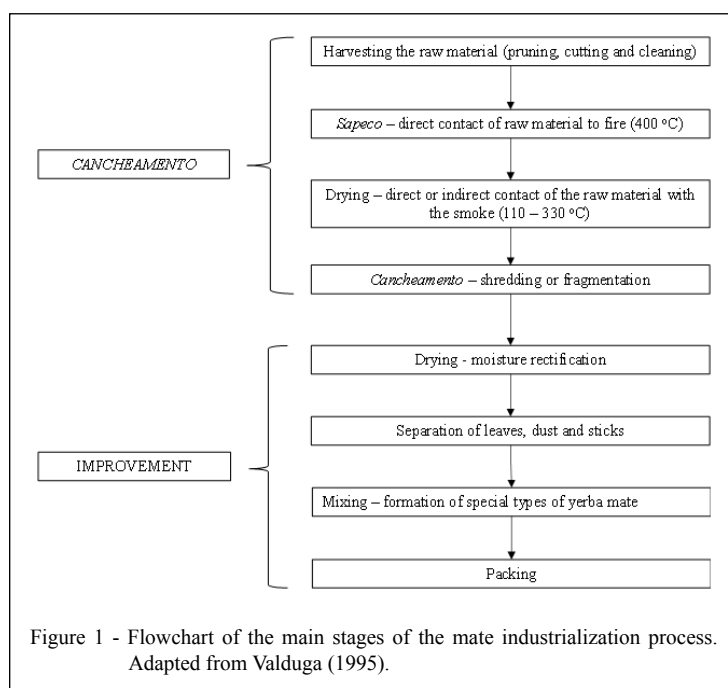
The mate industry has benefited from the preparation of several types of drinks (ESMELINDRO et al., 2002; SOUZA & LORENZI, 2005). Besides this application, mate has the property of being a central nervous system stimulant, attributed to the contents of methylxanthinic alkaloids, such as caffeine, also being known to contain compounds with antioxidant properties, such as phenolic acids (FILIP et al., 2000; BRACESCO et al., 2003; BRAVO et al., 2007; DELADINO et al., 2008; MACHADO et al., 2012; CHEMINET et al., 2021). Other effects of mate have been reported, in order to explain its popular usage, for instance, hepatoprotector, choleric,

diuretic, hypocholesterolemic, anti-rheumatic, anti-thrombotic, anti-inflammatory, anti-obesity and anti-aging (GORZALCZANY et al., 2001; SCHINELLA et al., 2005; MENDES & CARLINI, 2007; PANG et al., 2008; SILVA et al., 2008; PIOVEZAN-BORGES, 2016; ALVES et al., 2020). A growing number of publications on the functional properties of mate, through research carried out in the producing regions, and in developed countries, recommend the consumption of products derived from mate, widening the interest in other applications, such as medicines and cosmetics (GORZALCZANY et al., 2001; LUNCEFORD & GUGLIUCCI, 2005; SCHERER et al., 2006; HECK & MEJIA, 2007; MENDES & CARLINI, 2007). However, despite the growing consumption of mate and interest from the chemical and pharmaceutical industries, spread through investigations on the properties of this plant, the technological resources used in the industrialization of mate have been limited (Figure 1). As a consequence of this, it can be verified that there is a need to implement control of the production processes making them more efficient, reducing the exposure of the leaves to the smoke and also to the high heating temperatures which generate toxic compounds such as polycyclic aromatic hydrocarbons (CAMARGO & TOLEDO, 2002; ZUIN et al., 2005; VIEIRA et al., 2010).

No studies have been published to date describing the thermal map of the various stages

of mate processing, which demonstrated the need for future studies and a bettering of the processes and energy saving. Thus, there is still a need for improvement in relation to the quality of the traditional products based on mate, since the processes of production and industrialization have evolved little and the quality attributes of the products must be evaluated. Improvements in the process, from *sapeco* to drying, can contribute to the safety of the final product, avoiding the formation of chemically undesirable compounds, such as: naphthalene, phenanthrene, benzo[g,h,i]pyrene, fluoranthene, anthracene, benzo[a]pyrene, acenaphthene, benzo[k]fluoranthene, pyrene, dibenzo[a,h]anthracene, acenaphthylene, benzo[b]fluoranthene, chrysene, benzo[a]anthracene, fluorene, indene [1,2,3-c,d] pyrene (considered as carcinogenic compounds) (VIEIRA et al., 2008), collaborating to widening the spectrum of mate use, considering its proven medical properties. Success in improving the quality may lead to an increase in the demand for mate and in the added value of the product (BERTONI et al., 1992).

The consumption of mate on the market has progressively evolved; however, the product is commercially and industrially limited. The best possibilities for broadening the market seem to be offered by the modernization of the production, where technological adaptation and optimization of the processes are fundamental, besides the diversification of



the products offered (CAMPOS et al., 1996; VIEIRA et al., 2008; MURAKAMI et al., 2011; BOAVENTURA et al., 2015). With the aim of monitoring the processing and defining the thermal map during the mate production, this study described the mate processing, including the thermal analysis of conventional processes of *sapeco* and drying and the establishment of a simplified energy balance for the production of mate.

MATERIALS AND METHODS

Descriptions of the installations and thermal balance of mate processing

The exploratory-descriptive research was based on data collected in the town of Catanduvas located in the mid-western region of Santa Catarina State, through the collection of data related to the different stages involved in mate processing.

From the literature survey and field research (visits to four mate processing units located in the municipality of Catanduvas), carried out with around 10 collaborators, 10 coordinators and 5 processing unit owners, the data related to the stages involved in the mate processing were obtained. The power consumed in the *sapeco* and drying was calculated from the information of the processors, regarding the consumption of firewood to mate drying and *sapeco* steps. According to the properties of the wood used (low calorific power of pine in kJ/kg of firewood), calculated from the density of the firewood, the power consumed was determined.

Evaluation of temperature of mate processing

The evaluation of temperatures of mate processing was carried out at 15 points on the equipment (*sapegador* and dryer), at two mate processing units, with the use of an infrared thermometer (Raytek, model PhotoTemp MX6, temperature range from -30 to 900 °C, with the emissivity regulated in the equipment software, adjusted to the required measurements (ϵ 0.80), with three measurements carried out at each point, keeping the equipment accuracy at 0.75%, spectral range in 1 a 1000 μm . The points monitored at the installations studied are shown in figure 2 (1-15).

Thermography

In order to evaluate the thermal environment to which the mate leaves are subjected thermographic images were used, taken with a thermographic camera (ThermoCam S 65 – Flir Systems, calibrated for up to 1500 °C), of the furnaces of two mate processing units. The temperature was monitored through the

hot extremities of the objects (metal plate) inside the furnace, subject to the same radiation and convection to which the leaves are submitted.

Moisture determination

Moisture of mate leaves was determined by drying to constant weight at 105°C (AOAC, 2005; BASTOS et al., 2006).

RESULTS AND DISCUSSION

Description of the installations

The processing of mate has undergone little modernization over the years, still following the sample principle of rudimentary installations used by the Indians, and therefore there remains many aspects which need to be improved compared with other agroindustries. The mate processing units visited use the mechanized system and possess the same type of industrial installation to scorch and dry the mate. Two wood burning furnaces (1000 – 1500 kg/hour of mate leaves) are used, interconnected with rotary drying cylinders.

The images of the mate processing stages collected at the processing units under study are shown in figure 3, which follow the same operational sequence as the mate processing.

The leaves and green stems of the mate are unloaded from trucks (Figure 3A) and spread on a conveyer-belt (Figures 3B and 3C), which transports the mate onto the furnace flames of the scorcher. During the *sapeco* the flame is maintained, generated from the wood burning (Figure 3D), and the leaves and stems are fed into the equipment falling through the flames (Figure 3E). After being submitted to high temperatures, the leaves and stems circulate inside a rotary drum (iron cylinder) (Figure 3F), which apart from the gyrating movement has internal fins to facilitate the exit of the scorched material (Figure 3G). In this first stage, the leaves undergo a pre-drying process, since they enter with approximately 60% moisture content and leave scorched with a moisture content of around 35%.

The objective of the *sapeco* is to remove the superficial moisture and inactivate enzymes (peroxidases and polyphenoloxidases) which cause plant biomass oxidation, turning the leaves dark and the taste unpleasant (VALDUGA, 2002; NABECHIMA et al., 2014). This production system is currently mechanized; however, it follows the same principles practiced by the Indians who, manually, passed in a fast manner the raw material of stems with leaves over the flames of a wood fire, suitable for this purpose.

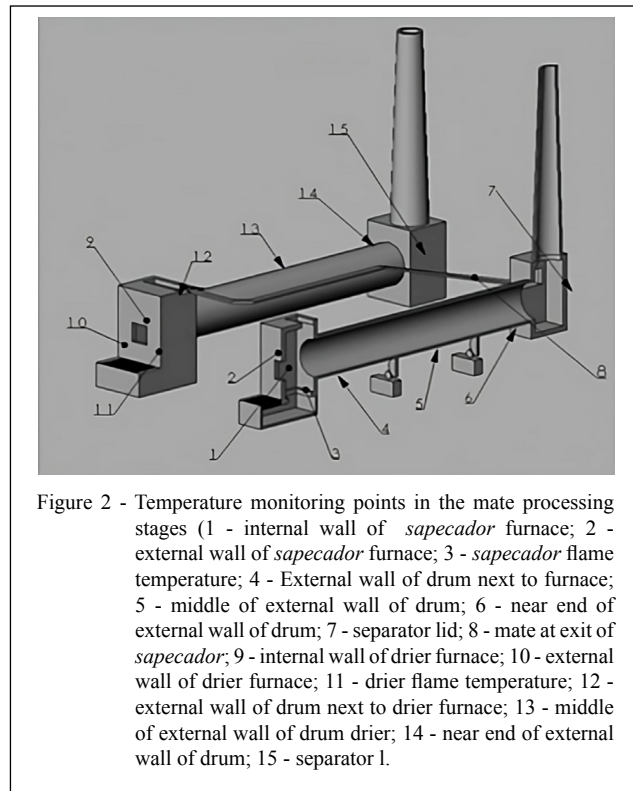


Figure 2 - Temperature monitoring points in the mate processing stages (1 - internal wall of *sapecador* furnace; 2 - external wall of *sapecador* furnace; 3 - *sapecador* flame temperature; 4 - External wall of drum next to furnace; 5 - middle of external wall of drum; 6 - near end of external wall of drum; 7 - separator lid; 8 - mate at exit of *sapecador*; 9 - internal wall of drier furnace; 10 - external wall of drier furnace; 11 - drier flame temperature; 12 - external wall of drum next to drier furnace; 13 - middle of external wall of drum drier; 14 - near end of external wall of drum; 15 - separator I.

After the *sapeco*, the leaves are collected at the end of the rotary drum in a transport system which sends them to the dryer (Figure 3H). The equipment used for the drying is similar to that used for the *sapeco*; however, it uses a milder flame in the

furnace and dehydrate the leaves until they acquired a breakable and crisp texture.

The raw material enters the dryer with a moisture content of around 35 % and exits with approximately 6 %. Besides the mechanical rotary



Figure 3 - Main stages of mate processing. 3A - Mate reception area; 3B and 3C - mate entering the process; 3D e 3E - mate *sapeco*; 3F e 3G - mate drying; 3H - external view of the *sapecador* and mate dryer; 3I - mate crushing.

dryers (Figure 3H), there are also conveyer-belt dryers. According to ESMELINDRO et al. (2002), the main difference between the two types of dryers is related to the contact of the raw material with the smoke during the drying process. The rotary dryer is the system most commonly used in the Brazilian market, with low industrialization and installation costs, easy handling and with no risk of damage by fire (SCHIFFL, 1997, cited by BOUGARDT, 2000); however, it has the disadvantage of direct contact of the smoke with the product, which is not observed in the conveyer-belt dryer, since the contact is indirect, causing less damage to the raw material.

After drying, in the final process, the mate is triturated or fragmented in an iron or hardwood triturator called a *soque* (Figure 3I). This apparatus forms part of the typical production system, where the triturated mate is called *cancheada*, constituting, thus, the raw material for the production mills, particularly for the commercial types: tea, *chimarrão* and *tererê*.

In the *sapeco* and drying stages, the contact of the raw material with the smoke from the wood burning, with compounds as carbon monoxide, methane, aldehydes, volatile organic compounds (C2 – C7), substituted furans, benzene, toluene, acetic acid, formic

acid, nitrogen oxides (NO and NO₂), sulfur dioxide, methyl chloride and others) (TORRES-DUQUE et al., 2008), and high temperatures, contributes significantly to the generation of compounds called polycyclic aromatic hydrocarbons (PAHs), which represent an important class of carcinogens formed during the incomplete combustion of organic material (CAMARGO & TOLEDO, 2002; ZUIN et al., 2005). However, these are present in many foods (MORET & CONTE, 2000; LIU & KORENAGA, 2001; TFOUNI et al., 2007; STUMPE-VIKSNA et al., 2008; REY-SALGUEIRO et al., 2008).

The removal of wood as a heat source for the process would bring advantages in terms of the reduction of these compounds, as well as facilitate the control of the temperature to obtain a product with quality and homogeneity. Avoiding the direct flame and controlling the temperature can minimize the generation of PAHs both through the contact with combustion gases and the formation these pyrolysis compounds from superheating of the leaves.

Thermal balance of the mate processing

In interviews with the production managers and staff at the units, it was possible to collect data for a simplified energy balance, as presented in table 1.

Table 1 - Estimate of thermal yield for the mate *sapeco* and drying processes of four processing units located in the municipality of Catanduvas.

-----Mate Processing Units-----					
		A	B	C	D
-----Data to calculate thermal yieldA-----					
Processing of crude mate	kg/h	1200	1300	1100	1200
Mate delivered for packaging	kg/h	400	433	330	400
Wood yield per ton of raw mate (st)	m ³ / ton	1	1	1	1
% wood consumed during <i>sapeco</i>	%	70	70	70	70
% wood consumed during drying	%	30	30	30	30
Weight per m ³ of pine (st)	kg/m ³	400	400	400	400
Moisture content of pine on a wet basisB	%	20	20	20	20
Low calorific power (LCP) of pineC	kJ/kg	17000	17000	17000	17000
Moisture content of leaf on a wet basisD	%	58	58	58	58
Moisture content of ready mate D	%	6	6	6	6
-----Evaluation of thermal yield-----					
Power consumed in <i>sapeco</i> and drying	kW	2133	2502	1603	2133
Evaporated water mass	kg/h	667	722	611	667
Latent heat of water vaporization	kJ/kg	2440	2440	2440	2440
Useful heat for water evaporation	kW	452	490	414	452
Power percentual for water evaporation (drying)*	%	21	20	26	21

st: estimated value; A: Data obtained from interviewing collaborators, coordinators and owners of four mate processing units in the municipality of Catanduvas. B: Source: SANTINI & MATOS (1995), C : Source: QUIRINO et al. (2005), D: Source: BASTOS et al. (2006).

(*) Percentage of power corresponding to drying (obtained from power consumed in *sapeco* and drying).

It can be noted that in the unit reports were obtained with very similar data regarding the wood yield and the productivity.

The thermal balance allowed it to be estimated that the *sapeco* stage is characterized by a higher expenditure of energy in the process and that only 20 - 26 % of the energy is effectively consumed in the evaporation of water from the mate leaves. These results verified the need for immediate action, both for energy saving and temperature control to avoid the formation of compounds toxic to human health (PAHs), derived from the pyrolysis of the leaves and wood combustion gases. In comparison, the efficiency of combustion engines, for instance, despite being modern, is around 35 - 40% (DAHAM et al., 2022) and the mate processing would be around 50% efficient, despite being rustic. However, the restrictions on energy consumption from the environmental and economic point of view, require efforts both for the diagnosis and designing of new projects for more energy efficient mate processing.

The units visited do not use thermal insulation on the furnace surfaces, the transporting systems and the rotary drum. This leads to an important loss of heat from the system which could be avoided.

Evaluation of temperature of mate processing

Table 2 gives the temperature values reported in the mate processing stages in processing units. The two units evaluated had similar temperature values during processing, and the temperatures during *sapeco* are higher than those during drying, according to the literature (ESMELINDRO et al., 2002).

The evaluations carried out indicated that the energy consumption in the *sapeco* operation exceeds that required for this operation. The literature has cited values of around 400 °C as sufficient to inactivate enzymes and maintain the green color of the leaves (ESMELINDRO et al, 2002), while NABECHIMA et al. (2014), indicated that the temperatures practiced should be sufficient for the inactivation of mate peroxidases (around 255 °C). The temperatures evaluated in the internal parts of the *sapeco* equipment and at the point where the leaves enter reach values of 540 to 560 °C, which generates a loss of energy, besides a tendency toward a greater formation of polycyclic aromatic hydrocarbons, carcinogenic compounds generated by the burning of organic material at high temperatures. Therefore, future studies are required to establish a better thermal regime in the mate processing.

Table 2 - Temperatures (°C) during the processing (*sapeco* and drying) of mate at the processing units in the municipality of Catanduvas (Santa Catarina State, Brazil).

	Unit A	Unit B	
-----Temperature (°C) -----			
-----Furnace and rotary drum for <i>sapeco</i> -----			
1	Internal wall of furnace	540	560
2	External wall of furnace	60	60
3	Flame temperature	800	800
4	External wall of drum next to furnace	270	280
5	Middle of external wall of drum	150	160
6	Near end of external wall of drum	100	110
7	Separator lid	50	54
8	Temperature of mate at exit of <i>sapegador</i>	35	37
-----Furnace and rotary drum for drying-----			
9	Internal wall of furnace	350	370
10	External wall of furnace	40	40
11	Flame temperature	500	500
12	External wall of drum next to furnace	90	97
13	Middle of external wall of drum	85	87
14	Near end of external wall of drum	80	82
15	Separator lid	32	32
16*	Temperature of mate at exit	54	56

(*) Point not presented in Figure 2, temperature of the mate leaf.

The residence time and the average temperature of the mate in the dryers are dependent on the operating characteristics of each one. In the rotary dryer the product remains in direct contact with the smoke for approximately 30 mins, with the temperature oscillating from 350 – 370 °C, at the entrance of the dryer, and from 80 - 82 °C at the exit; these values are similar to those reported by ESMELINDRO et al. (2002), which were an average of 350 °C at the entrance and 110 °C at the exit of the dryer. For the conveyer-belt dryer, little used in Brazil, the average time is 3 hours and the temperature varies between 90 and 110 °C.

Thermography

To evaluate the thermal environment to which the mate is exposed during processing, the temperature at the hot extremities of the objects (metal plate) inside the furnace was monitored. Table 3 gives the temperatures observed (thermographic camera) in the sapeco stage of mate processing at the four of mate processing units studied.

The temperature to which the leaves are submitted during *sapeco* lies at around 540 – 620 °C, differing from the literature which reports the average temperature at the scorcher entrance as being around 400 °C (ESMELINDRO et al., 2002). Some authors stated that the quality of the final product can be affected by a thermally inefficient treatment due to the exposure to temperatures lower than those recommended during *sapeco*, allowing residual enzymatic action or contrarily to exposure to high temperatures causing the burning of the product (ESMELINDRO et al., 2002; VIEIRA et al., 2010;

NABECHIMA et al., 2014), besides the possibility for greater generation of polycyclic aromatic hydrocarbons.

This preliminary research about the thermal condition of mate (*Ilex paraguariensis*) processing, in addition to stimulating new research for the enhancement of functional properties, avoiding the formation of PAHs in mate, also contributed to alerting about the need for changes in industrial processes. Despite the positive scenario, based on the properties of mate, the vast majority of processors are unaware of or neglect these needs for changes that could bring even more benefits to the health of consumers and new business opportunities for importing countries that despite recognizing the benefits of mate, have strict control over the presence of PAHs.

CONCLUSION

Results of this study verify that improvements need to be made to the mate processing for which 80 % wastage of the energy produced occurs, along with high temperatures originating from this process.

It is shown with the use of evaluations with a thermographic camera and thermometry that the mate sector needs to change the *sapeco* and drying systems, in order to save energy and, consequently, better regulate the processing temperature, resulting in product improvement.

The design of a new process focusing on energy saving, the integration and improvement of the performance of all economic aspects in the processing and promotion of the product, and the production process of mate in the producing states,

Table 3 - Temperatures prevailing during the mate *sapeco* process, evaluated with the aid of a thermographic camera, in the four mate processing units studied.

		-----Unit-----			
		-----A-----	-----B-----	-----C-----	-----D-----
		-----Temperatures (°C)-----			
		-----Furnace and rotary drum for <i>sapeco</i> -----			
1	Internal wall of furnace	810	987	890	880
2	Object or extremity subject to the flame temperature	540	575	560	620
3	External wall of furnace	50	50	50	50
4	Flame temperature	1030	1040	1070	1100
5	External wall of drum next to furnace	180	250	265	200
6	Middle of external wall of drum	120	150	115	150
7	Near end of external wall of drum	100	120	100	100

could represent a significant step toward the adding of value to this important culture.

ACKNOWLEDGMENTS

We thank the FINEP/SEBRAE for their financial support, and Ms. Jozeane Caldartt, and Mr. Anselmo Zanelatto (*in memoriam*) by support in mate industries.

DECLARATION OF CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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