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The *solera* system for ageing wines and spirits: A graphical model
El sistema de solera *per a la criança de vins i begudes espirituoses: un model gràfic*

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Abstract: The *solera* system for ageing wines and spirits is a dynamic method in which the contents of the upper casks (younger) is slowly mixed with that of the lower casks (older) until it is bottled. In this article, a graphical method generated with a spreadsheet is proposed. The time/age evolution of all levels of the *solera* system can thus be tracked and visualized.

Keywords: *Solera* system, ageing of spirits, Jerez, sherry, brandy.

***Resum: El sistema de* solera *per a la criança de vins i begudes espirituoses és un mètode dinàmic en què el contingut de les botes superiors (més jove) es va mesclant a poc a poc amb el de les botes inferiors (més vell) fins que és embotellat. En aquest article es proposa un mètode gràfic fet amb un full de càlcul que permet visualitzar i seguir l'evolució del temps d'envelliment en tots els nivells del sistema de* solera.**

Paraules clau: Sistema de* solera*, criança de licors, xerès, brandi.

Introduction

The improvement of organoleptic qualities of wines and spirits achieved through their ageing in wooden barrels (and in particular oak barrels) has been known for centuries. Aged wines and spirits are highly appreciated by consumers and therefore they are very important from an economic point of view as well. There are essentially two ways to age wines and spirits: the static method, which simply consists of storing the alcoholic beverage in a wooden cask for a certain amount of time until it is bottled, and the dynamic method. The latter, which is better known as the *solera* system, involves a set of stacked casks from which only a fraction of the ground level casks (the *solera*) is retrieved for bottling. This fraction is then replenished with the same amount from upper casks (the *criaderas*), until finally new wine or freshly distilled spirits fill the top level of casks (figure 1). The *solera* system was developed in the Jerez area of Andalusia (southern Spain) for the production of sherry wines and brandies. However, it is also used in other countries for the production of sherries, port and fortified wines, rum, brandy, etc. [1]. Contrasting examples would be Brandy de Jerez, which is typically made by the *solera* system, and French brandies such as Cognac and Armagnac, which are aged by the static method.

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The *solera* system is labor-intensive but ensures a thorough mixing of the different barrels that yields a consistent, homogeneous beverage over the years. The transfer and mixing of variable amounts of the liquid also favors aeration and thus the oxidation of some of the compounds, contributing to flavor and taste [2-8]. Nevertheless, the organoleptic properties of aged wines and spirits are a very complex issue dependent on many factors besides time: type of grapes and terrain, winemaking method, distillation, storage conditions (temperature, humidity), and the cask and its previous content.

In this article I propose a simple graphical method generated with a spreadsheet to understand, compare and simulate ageing by the *solera* system. Some illustrative examples will be discussed and, lastly, a simulation based on a real example will be carried out.

Discussion

To begin with, a simple case of a 3-level system (two *criaderas* and one *solera*) will be discussed. Let's assume that one third of the *solera* is bottled every year, and therefore removed from the system. All levels have the same total volume. With the spreadsheet, one column (A) for time in years and one column for each level (B, C and D) are generated. All the casks are filled with new wine or distillate, and therefore after one year, the liquid on all the levels is one year old (line 1). Then one third of the *solera* level is removed and replenished with one third of the liquid from the level above,

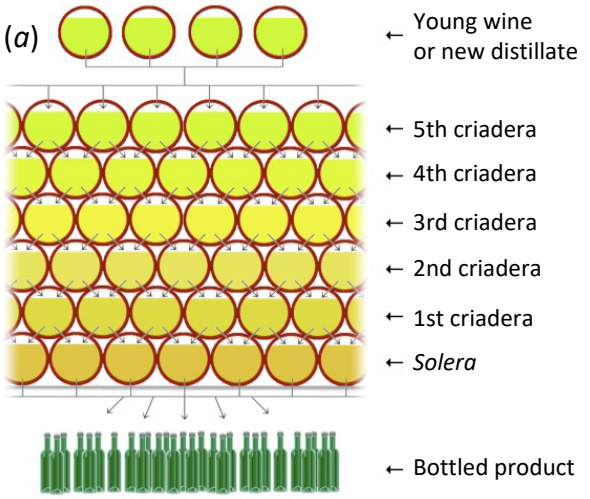

FIGURE 1. (*a*) The *solera* system for ageing wines and spirits (left). Adapted from Denkhenk – Own work, CC BY-SA 3.0, *https://commons.wikimedia.org/w/index.php?curid=12367724*. (*b*) An example of the *solera* system in the Jerez area (right). From Anual – Own work, CC BY-SA 4.0, *https://commons.wikimedia.org/w/index.php?curid=68975178*.

which is in turn replenished with one third of the liquid stored in the upper level. Eventually, this upper level is filled (to one third of its volume) with new wine or distillate. After one more year (line 2), we formulate this in the *solera* as B2=+(0,6666*(B1+1))+(0,3333*(C1+1)), in the first *criadera* as C2=+(0,6666*(C1+1))+(0,3333*(D1+1)), and in the second *criadera* as D2=+(0,6666*(D1+1))+(0,3333*1). These formulae are then copy-pasted to as many years as desired and the time/age plots can be constructed (table 1). The amount of liquid retrieved can be modified very easily and to change the time scale (for example to simulate the liquid retrieved every six months), fractions can be used in the formulae and the time column A. Lastly, more columns can be added to simulate more levels. A plot for different cases of the 3-level *solera* system was constructed in this way, as shown in figure 2.

It may be immediately noted that the *solera* system leads asymptotically to a particular ageing: the smaller the fraction re-

TABLE 1. Spreadsheet results for the first ten rows (years) in a 3-level *solera*, 33% retrieval per year simulation. Source: Prepared by the author.

Year	*Solera*	2nd level	3rd level
1	1	1	1
2	1,9998	1,9998	1,6665
3	2,99950002	2,88841113	2,1107889
4	3,96207414	3,6288408	2,40695188
5	4,85051126	4,22112234	2,60437412
6	5,64015088	4,68173805	2,73597579
7	6,32004787	5,03264731	2,82370146
8	6,89022526	5,2958024	2,88217939
9	7,3580151	5,49071227	2,92116078
10	7,73480726	5,63363169	2,94714578

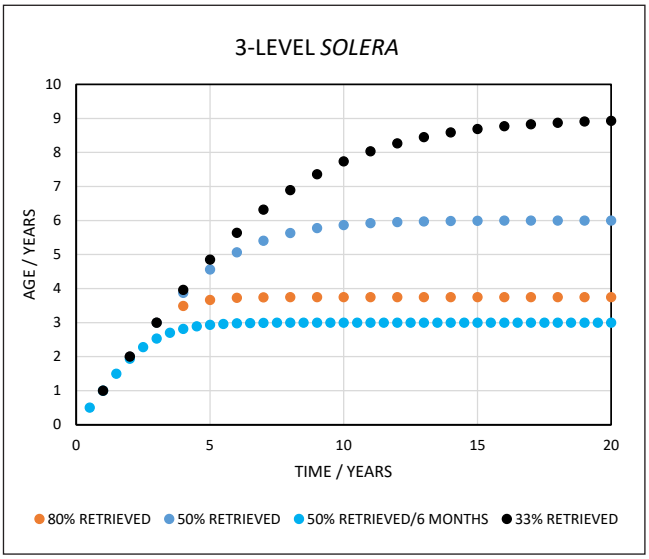

FIGURE 2. Age vs. time plot for several fractions retrieved from a 3-level *solera*. Source: Prepared by the author.

trieved, the older the liquor will be when the system stabilizes. Hence, removing one third of the *solera* every year will consistently lead to a 9-year-old product, but this will begin to occur after 16 years! (figure 2, black dots)

Of course, it might be impractical from an economic standpoint to keep such a 3-level *solera* system operational, and therefore larger fractions of liquid are usually removed and bottled. Still, bottling 50% of the *solera* level every year would lead to a 6-year-old liquor after 10 years, and bottling 80% of the *solera* level would produce a *ca.* 4-year-old spirit after 6 years (figure 2, dark blue and orange dots, respectively). In practice, fractions are retrieved more than once a year to facilitate production. For example, retrieving 50% of the *solera* twice a year would lead to a 3-year-old beverage after 4 years of operation (figure 2, light blue dots).

If longer ageing is required, for example to produce higher-end ports and brandies, it is more convenient to use bigger *solera* systems and to bottle relatively large fractions more than once per year. In figure 3, a representative example of the ageing achieved with different *solera* systems over time is shown for a 50% retrieval every six months. As commented previously, a 3-level *solera* system achieves a 3-year-old product after ca. 4 years (figure 3, light blue dots). In contrast, a 5-level system leads to a 5-year-old beverage after 7 years of operation and a 10-level system leads to a 10-year-old product after 13 years (figure 3, orange and violet dots, respectively). So as a rule of thumb, the number of levels of the system defines the age of the final product upon stabilization as long as 50% of the *solera* level is retrieved every six months. Different fractions and numbers of retrievals per year would lead to different results.

An interesting point of the spreadsheet approach used here is that actually the age of the liquid contained in any level is known and, therefore, the evolution of the whole system (not just the fraction to be bottled) is determined (figure 4). For example, this would be useful if it was necessary to know the age of a particular level to be transferred to a different *solera* system or for blending before reaching the final level.

Lastly, we now discuss a real case as an example. Cardenal Mendoza is a classic well-known brand of Solera Gran Reserva Brandy de Jerez. In its webpage, the company claims that it is aged for 15 years on average, and it provides some details on its production too: its *solera* system has 8 levels and a maximum of one third of the *solera* level is bottled (no information is provided on how often). Moreover, the young distillate used to refill the 8th level has been aged (statically?) for 3 years [9]. With this information, two simulations were carried out, using either one or two retrievals per year (figure 5). It is clear that one retrieval per year for bottling would lead to a highly aged brandy (*ca.* 25 years) after a very long time of operation, whereas two retrievals would lead to a 13 year-old brandy in a much shorter time, which is fairly close to the cellar's claims.

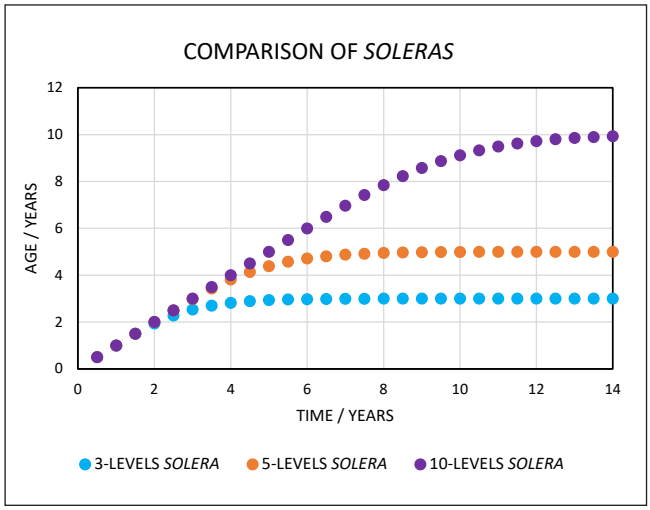

Figure 3. Product age achieved by *solera* systems with different levels, retrieving 50% of the *solera* volume every 6 months. Source: Prepared by the author.

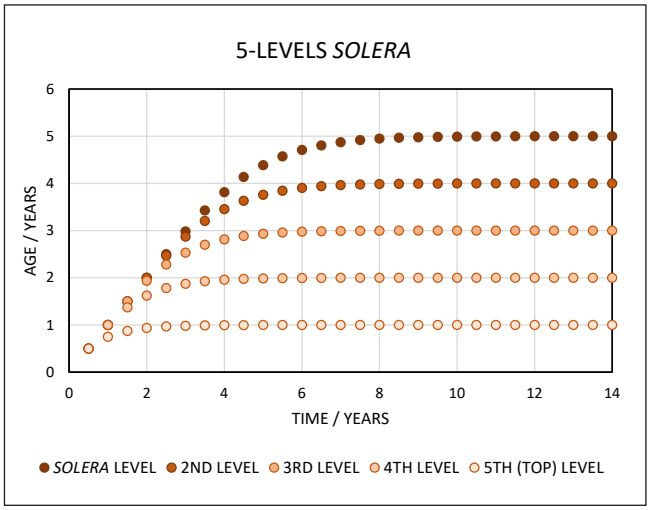

Figure 4. Age achieved for every level in a 5-level system retrieving 50% of the *solera* volume every 6 months. Source: Prepared by the author.

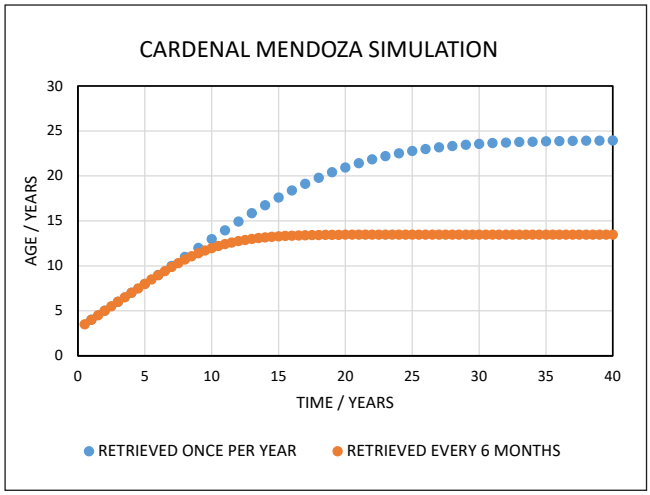

Figure 5. Simulation of Cardenal Mendoza ageing, retrieving 33% of the *solera* brandy once (blue dots) or twice (orange dots) a year. Source: Prepared by the author.

Concluding remarks

Spreadsheets are a useful tool to understand and simulate how a *solera* system for the ageing of wines and spirits works. This method allows us to understand the ageing process at each level (*solera* and *criaderas*) over time, considering the parameters that affect ageing exclusively: the number of levels of the *solera* system, the fraction removed from the *solera* every year and the frequency of removal, and even the age of the new liquid introduced into the system (as we have seen in the Cardenal Mendoza simulation). Although we have not considered the angels' share (the amount of liquid that evaporates due to the transpiration of oak casks), this parameter can be easily included into the calculations, too.

Conflicts of interest

The author declares no conflicts of interest. The only reason for using a particular brand for the final simulation has been the availability of public data on its *solera* process.

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