Data Analysis in a Batch Salami Ripening Chamber for Real-Time Process Monitoring and Control

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Abstract — **The paper provides an analytical and visual view of what actually happened – on the process side – in a fully instrumented, pilot-scale, air ascending-flow chamber of industrial type for salami ripening. Since ripening is always characterized by a "slow" dynamics and limited variations in process variables, the time course of the curing air temperature and humidity, as well as the sausage heart temperature, did not show rapid or incomprehensible transients. The monitored variables clearly showed limited amplitude oscillations due to the "go" and "stop" air circulation pattern, that is the sequence of phases with either forced or natural circulation in the cell as imposed by the supervision system for the automatic control of the chamber set points. The effectiveness of set point tracking was favorably assessed for the experimental tests. Then, comparisons were made between different measurements of the same variable, e.g., air temperature and humidity, monitored by probes at different heights in the chamber; similarly, the temperature measured by a TC at the heart of the sausage was matched to the curing air temperature in the chamber. From these comparisons and other crossed checks among data, it was possible to obtain static (e.g. the effect of the position on air temperature at equal height) and dynamic (e.g., the sausage temperature response to the temperature variations in the chamber) assessments of the process variables.**

All in all, the work done and its further exploitation offer a tool set for a real-time aid to a factory operator.

Keywords [1] — **time series, data analysis, moving average, automatic control, set point tracking, salami, drying, ripening**

I.   Introduction

Ventilated and instrumented ripening chambers are nowadays the process plants for the production of traditional meat-based food like salami at industrial scale.

Among the several and concurrent steps, either physical or biological or chemical, determining the features of the final product, the largely prevailing mechanism is the salami

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dehydration. The whole sausage ripening process consists of a sequence of phases, as the following (Zambonelli et al., 1992):

- **1st phase: stabilization** of the introduced product. Chamber temperature: 5-7°C. It is aimed at obtaining a uniform product temperature, before start-up of the drying process. This phase is used only if the product loading time in the chamber is high and so it is necessary to avoid initial temperature differences.

- **2nd phase: low temperature drying** at 7-8 °C. This phase allows a weight loss of 2% in 12-20 hours and guarantees drying of the casing, which are very moistened because just washed. Only a few producers are equipped and actually adopt this phase.

- **3rd phase: heating**. In this phase, the product attains a core temperature of about 18-20°C; the duration of the heating stage is a function of the chamber temperature, the sausage size and shape and the meat quality. A small weight loss is allowed by controlling the chamber relative humidity (RH). In this phase, temperature and a high humidity facilitate the sausage typical fermentation, which will give the distinctive taste and characteristic flavor.

- **4th phase: actual drying**. A strong dehydration and a drop in the chamber temperature characterize this phase, which results in the end of the above said fermentation. Beginning temperature: 18-22°C, RH: 50-75%.

- **5th phase: ripening**. This phase is a drying phase too, but at a milder rate. The chamber temperature decreases from an initial value of 17°C down to 12-13°C; RH is about 55-85%.

Design, operation and control of a ripening chamber play a key role in ensuring uniform circulation of curing air within the volume occupied by sausages and, hence, quality, safety and consumer acceptance of products.

On-line monitoring and data acquisition in industrial salami ripening is not very much treated in literature. Tradition and rules of thumb hold, whereas many actions and decisions are taken by process technologist on the basis of his personal experience and historical data log (Katz and Stinsky, 1987; Diaferia et al., 2011).

The Authors report on experimental tests of salami ripening carried out during a recent research project (PON "Safemeat"), which was aimed at developing innovative methods for the production of fresh and cured meat products, provided with a low-fat content and functional starters. Due to the big amount of data acquired for each test, the data analysis was first aimed at inspecting data congruity and reliability,

then at elaborating and comparing data for trend analysis, finally at checking the actual trends against the set point trajectory imposed for sausage drying and maturing.

II. Materials and Methods

A fully instrumented, pilot-scale, air ascending-flow ripening chamber has been used for the experimental test campaign (Autori Vari, 2013). It is located in the labs of the Experimental Station for Food Preserving Industry (SSICA) at Parma (Italy) and has a volume of about 10 m^3 and a max load capacity of 300 kg. Fig. 1 provides a schematic. The forced air circulation pattern, during which air moves at moderate velocity (i.e., less than 0.9 m/s) in the sausage load space, can be alternated to a "natural" circulation pattern by switching the fan off. A network of thermo-couples (TC) and hygrometric sensors (RH) suitably placed within the chamber and a software supervision system (PROGES) connected to the hardware equipment in the chamber allowed data acquisition and process control. Among the other things, air and sausage temperatures at various points of the cell, air humidity and air velocity were acquired and monitored. The sampling period was 1 min.

Generally, the measurements of air temperature and humidity in the rear part of the ripening chamber were preferred for subsequent analysis, because they appeared less affected by the frequent front door openings.
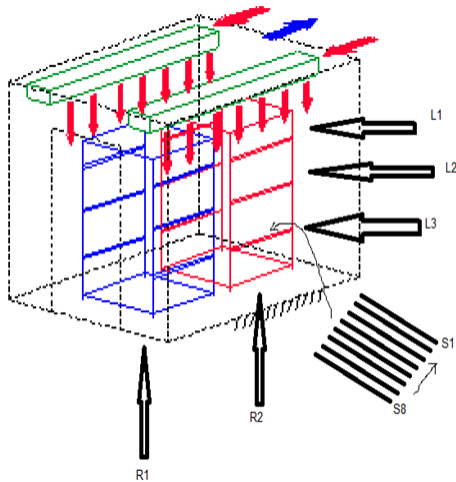

Figure 1.   A schematic of the SSICA pilot-scale ripening chamber with the notation adopted for racks, sticks and levels in sausage loading.

The salami under investigation were manufactured by Dodaro SpA (Spezzano Albanese, Italy) starting from a traditional recipe (i.e., "salsiccia dolce", 43-45 mm natural gut diameter) and imprinting the shape of a pseudo-cylindrical "stick" rather than the typical "horseshoe" to the fresh sausage. For each test, a batch of about 250 kg of fresh sausages was produced by Dodaro SpA and shipped to SSICA under refrigerated conditions (4-8 °C).

Four lengthy experimental ripening tests were carried out under controlled conditions. The Department of Industrial Engineering (DIIn) of the University of Salerno was in charge

of test programming. The four tests were different on both the product and the process side; therefore, not only the overall batch time, but also the fresh sausage recipe, the sausage distribution in the active volume of the chamber and the operating conditions for ripening were changed. For shortness and simplicity, only one of the four experimental tests is discussed in this work, precisely the test SSICA-2 carried out between November 18 and December 15, 2014.

III. Results and Discussion

A. Set Point Tracking

Temperature data acquired by the C31 probe, i.e., a TC placed in the rear part of the chamber (rack R2) on the last stick (S1) at the lowest level (L3) were used. The results are reported in Fig. 2A.

Throughout the whole test the air temperature always showed a moderate oscillation with a period of about 2-3 h and a width of about 1 °C. For most of the test and – surely – during the 5th phase (ripening), the recorded air temperature remained well within the set point dead band (i.e., the difference between the upper and the lower set point value), except for the initial heating phase (day 1) and the drying phase (day 2 to 4).

Also for tracking of the air humidity set point, the measurements of humidity were those in the rear part of the ripening chamber. Therefore, data acquired by the C28 probe, i.e., the RH sensor placed in the rear of the chamber (rack R2) on an intermediate stick (S4) at the highest level (L1) were used. The results are reported in Fig. 2B.

The RH data for set point tracking are a bit more troublesome than the temperature data in view of an easy interpretation. Throughout the whole test the air humidity always showed a substantial oscillation with a period of about 2-3 h and a width of about 20% RH units. This latter always appeared larger, twice and even three times, than the set point dead band. For the whole test duration, the oscillation band of the measured RH was not contained within the set point dead band and crossed its boundaries by an extent that varied depending on the sequence of phases in salami production. When approaching the end of the ripening phase (5th phase), the measured RH tended to cross the lower set point value and to remain mostly below it during oscillating.

Both the temperature and the RH oscillations are neither strange nor unexpected in a typical batch salami ripening operation. The oscillations, which are of a frequency by far lower than 1 Hz (see above), are originated by the typical "go" and "stop" air circulation pattern in the ascending-flow chamber, that is the sequence of phases with either forced or natural circulation in the cell. Such a pattern is imposed by the supervision system for the automatic control of the chamber set points and for the allowance of a "rest time" for the sausages under ripening. Independent calculations based on an *ad hoc* detection signal acquired by the supervision system as well as on the sampled measurements of air velocity at a fixed position in the chamber demonstrated that the typical "go" time takes from 6 to 9% of the overall test time.

When the lower RH set point value is met, the forced air circulation is "stopped", the curing air in the chamber becomes stagnant and at most undergoes a natural circulation pattern, which is well known to be by far less effective than forced circulation with respect to mass and heat transfer. As a result, the average humidity in the chamber is raised by sausage surface water evaporation, up to the point the upper RH set point value is reached. This event triggers the supervision system to switch the forced circulation on (i.e., "go" phase). Such a sequence is cyclical, with a period determined by the two characteristic times taken by the two different evaporation rates during natural and forced circulation, respectively, when "traveling" forth and back across the RH control dead band. As above said, the oscillation period is the same (i.e., 2-3 h) for both air temperature and humidity, but the oscillation width is much different, the larger one being for RH: simply, the thermal inertia turns out larger than the humidity storage capacity for the curing air in the chamber volume.

An attempt was made to offset the scatter of air humidity data as a function of the time and to make their trend sharper. To do so, the original RH data in Fig. 2B have been subjected to filtering by means of an unweighted, centered moving average (Murphy, 1999) with an order as long as 1000 times the sampling period of the supervision system. The resulting data series was plotted as a black curve overlapped to the reference RH data in Fig. 2B; the trend exhibited by such a curve fully reflects the previous discussion on tracking of RH set point. Based on this, one might state that the ripening process was unable to meet the RH set point in the chamber during the last four days, likely because of a too slow evaporation rate of the residual moisture from the sausages. Conversely, meeting the temperature set point was not a problem in last four days.

B. *Sausage vs Air temperature*

The available instrumentation allowed to monitor the time evolution of sausage temperature and then to compare it to that of curing air.

Data acquired by the C13 probe, i.e., a TC placed at the center of the rear wall of the chamber, and by the C20 probe were used, the latter being a TC stuck at the core of a preselected sausage that was placed in the rear of the chamber (rack R2) on an intermediate stick (S4) at the highest level (L1). The results are reported in Fig. 3A. The sausage core temperature always showed a moderate oscillation, with the same period and same width of the air temperature as discussed before. From the graph, it can be seen that the sausage core, initially at 18 °C, was brought to about 16.5 °C, then to about 14.5 °C and about 13.5 °C with some fluctuations during the initial phases (i.e., heating and actual drying). Later on, the ripening phase was slowly and progressively approaching a temperature of about 13 °C, that is the same final value of curing air. The time plot in Fig. 3A confirms that, as a result of sausage moisture evaporation (Bird et al., 2001), the air temperature profile is always located above the one of the sausage core temperature during the heating phase, the actual drying and part of ripening; at longer times, i.e., toward the end of the test, the temperature pattern

appears overlapped. Obviously, this means that the temperature driving force from the bulk of curing air to the individual sausage and, hence, the heat exchange rate are progressively decreasing with the time, being ultimately negligible toward the end of ripening.

Moreover, data acquired by the C21 probe were used, the latter being a TC bound to the surface of a preselected sausage that was located in the rear of the chamber (rack R2) on the left side of an intermediate stick (S4) at the highest level (L1). Fig. 3B reports the results, which strictly follow those of Fig. 3A. The sausage surface temperature exhibits a time profile with exactly the same features of the core temperature, that is a continuous, but moderate oscillation, step changes during the initial test phases, a progressive approach to the temperature of curing air (i.e., about 13 °C). Similar to the previous discussion, the time plot in Fig. 3B confirms that the sausage surface temperature profile is always located above the one of the core temperature during the heating phase, the actual drying and part of ripening, whereas the temperature patterns are almost overlapped at longer times. Again, this means that the temperature driving force from the surface to the core of an individual sausage and, hence, the heat exchange rate are progressively decreasing with the time, being ultimately negligible toward the end of ripening.

C. *Differences along the chamber height*

Fig. 4A reports temperature data acquired at increasing vertical quote in the rear part of the chamber (rack R2), that is by means of the C32 probe, a TC placed on the left side of the first stick (S8) at the lowest level (L3); the C30 probe, a TC placed on the left side of the first stick (S8) at the intermediate level (L2); the C24 probe, a TC placed on the left side of the last stick (S1) at the highest level (L1). The results in Fig. 4A allow discussing the change of the curing air temperature with height in the chamber. Just at a qualitative assessment, it can be easily seen that the data series at the highest level (L1) exhibits the lowest values when compared to the others, whereas the measured temperatures at the lowest level (L3) tend to be topmost. This is true in spite of the characteristic oscillations in Fig. 4A. The above finding perfectly reflects what is expected on the basis of the progress of heat exchange between the rising curing air stream and the hung sausages.

Fig. 4B shows air humidity data acquired at increasing vertical quote in the rear part of the chamber (rack R2), that is by means of the C35 probe, a RH sensor placed on the right side of an intermediate stick (S4) at the lowest level (L3), and the C28 probe, a RH sensor placed on the left side of an intermediate stick (S4) at the highest level (L1). For simplicity and a clearer presentation, each curve in Fig. 4B represents the trend exhibited by the moving average, calculated as said before, of the corresponding original data series. The black curve is just the same previously plotted in Fig. 2B (i.e., the moving average of the reference for chamber control). In this case the humidity measured at the highest level (L1) turns out generally lower than that measured at the lowest level (L3), whereas it should be the contrary. This is an unexpected finding, which is imputable very likely to inaccuracy of the

two RH sensors or, to some extent, to the difference in lateral position (right vs left side) of the two sensors in the chamber or to a possible stratification of moist air enhanced by the "stop" intervals in the air circulation pattern.

IV. Conclusions

The on-line monitoring, data acquisition and time series work out during experimental tests of salami drying and maturing in a fully instrumented, pilot-scale, ripening chamber of industrial type allowed assessing a successful set point tracking, as well as trends with time and differences induced by position of curing air temperature and humidity. In summary:

• Air temperature and humidity, as variables acquired by sensors subordinated to the automatic control system of the chamber, are consistent with the expected trend and the imposed set point changes.

• Measuring the actual temperature at the sausage heart provided an added value to the test outcomes and enabled the comparison with the sausage surface and curing air temperatures over time. This resulted in a perfect agreement with the expected heat transfer phenomena in the chamber.

• The change of curing air temperature with height in the chamber is consistent with the expected trend, with the temperature decreasing from bottom to top. Vice versa, there are uncertainties about the correctness of the corresponding change of air humidity.

Such a wide and easy-to-access data availability opens the possibility of using them for further and subsequent math modeling and simulation work on both the product and process sides.

Acknowledgment

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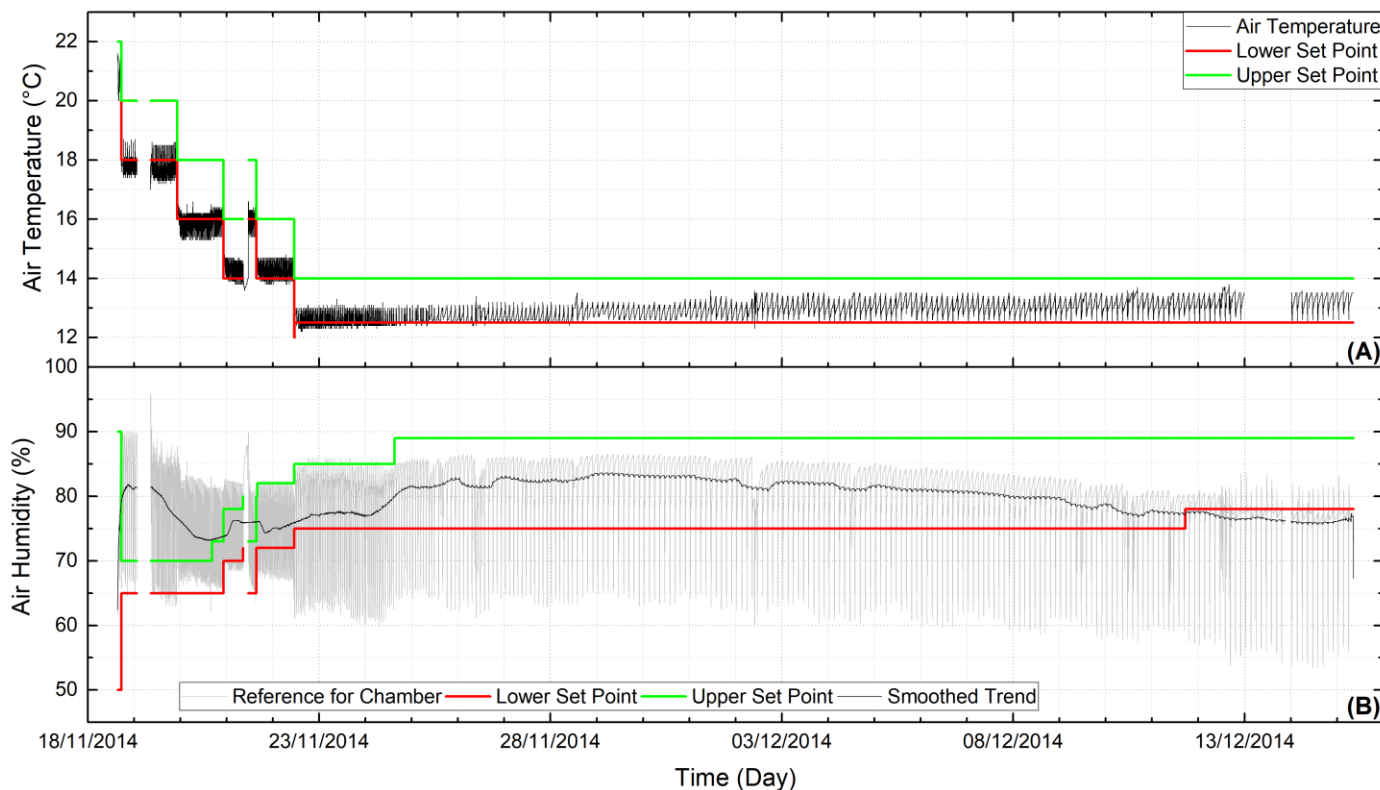
Figure 2.   Time plot with the set point thresholds in the ripening chamber: (A) air temperature and (B) air humidity reference and trend.
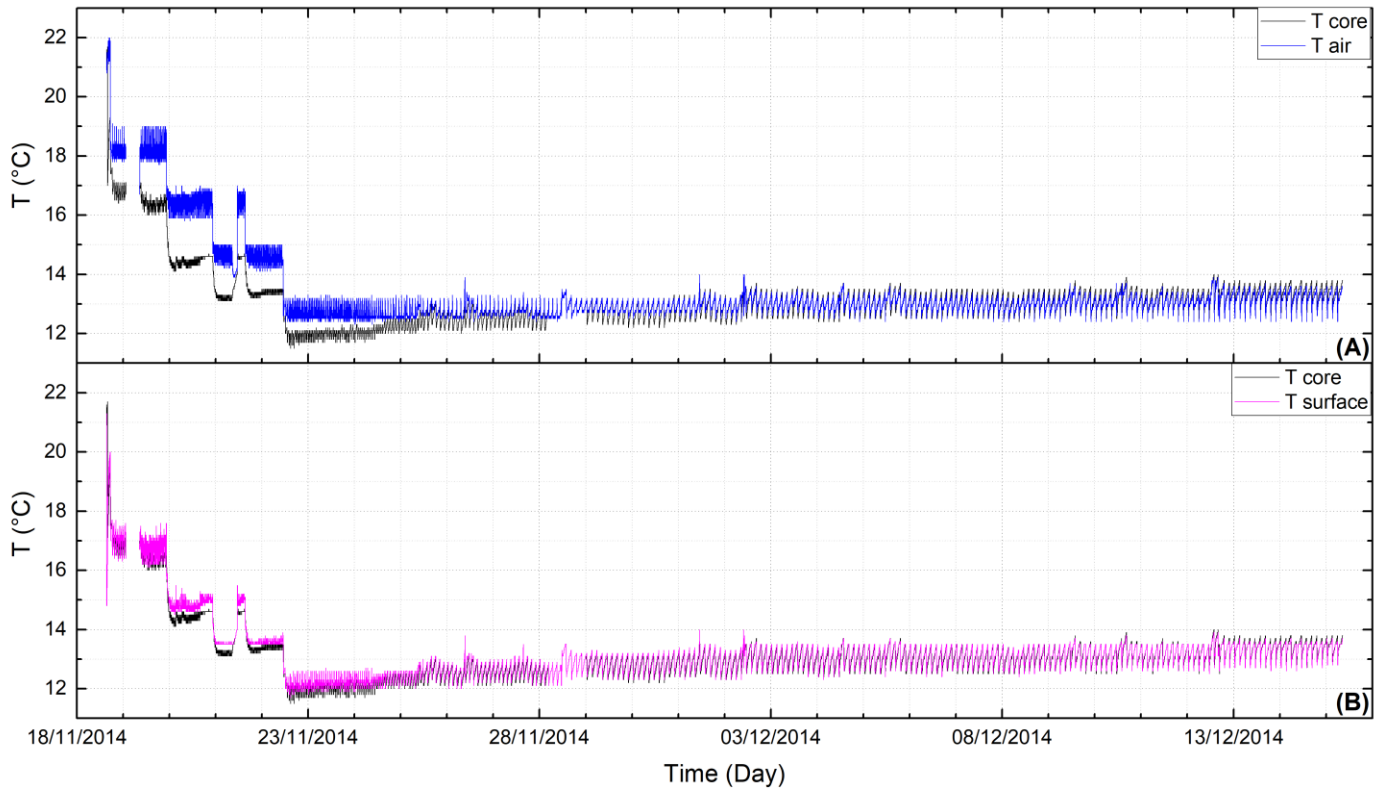
Figure 3. Comparison of the sausage core and air temperature (A), sausage core and surface temperature (B) in the ripening chamber.
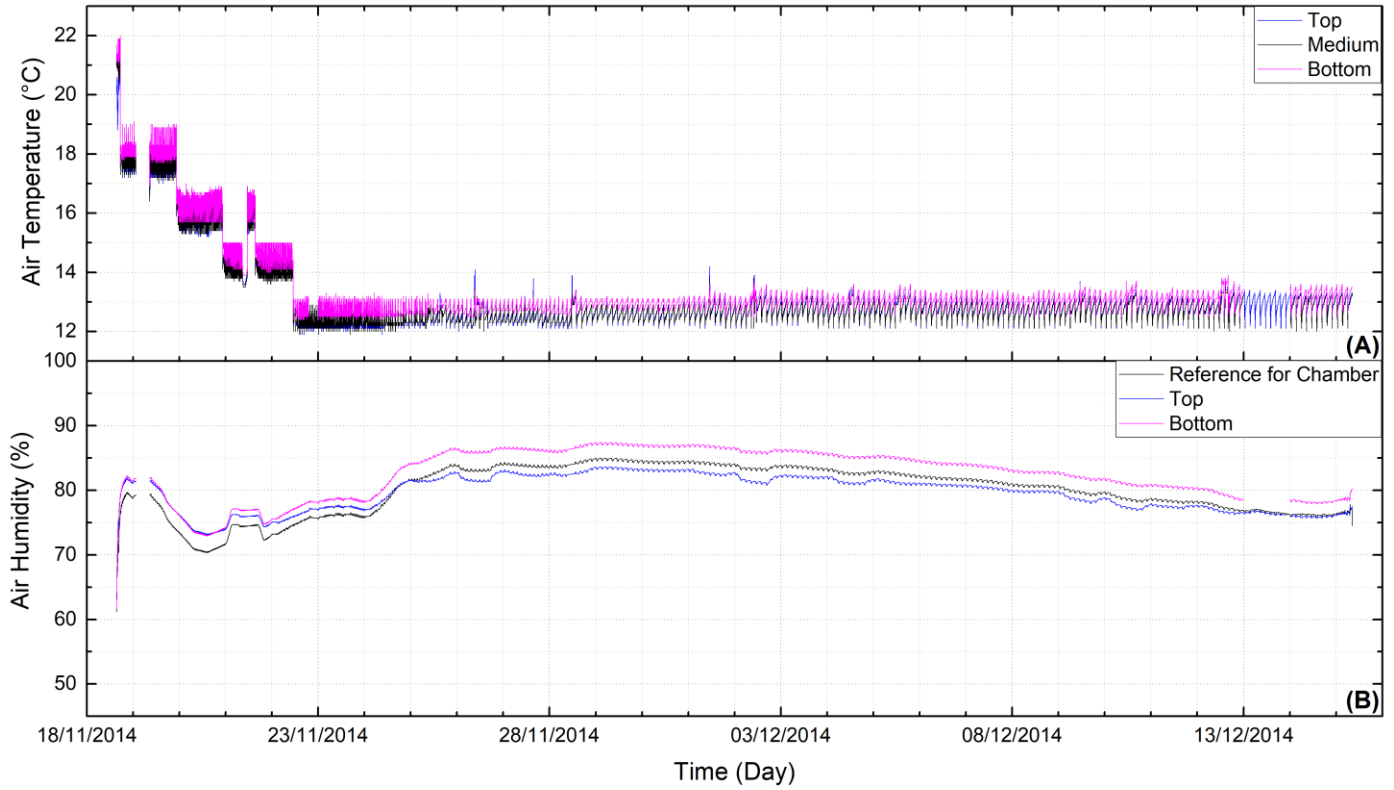

Figure 4. Comparison at different sampling points in the ripening chamber: A) curing air temperature at a top, medium and bottom position; B) air humidity at a top and bottom position.