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KEEPING IT REAL: STORING & PRESERVING GREEN COFFEE, PART 2 OF 2.

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IMAGINE THIS… You cup two superb coffees at origin, on two different continents, and both coffees score in the mid-90s. You purchase lots of both green coffees and 9 weeks later they are unloaded into your warehouse. One green coffee is packed in standard jute bags and the other arrives in vacuum-packed bricks. At the cupping table, the coffee from the jute bags is still good, but it has a hint of gasoline and loses 8 points, cupping out in the high 80s. But the vacuum-packed coffee tastes as it did at origin, still in the mid-90s!

A few months ago, motivated by similar experiences, we initiated some informal investigations into improved methods for preserving green coffee quality, as described in the previous issue of Roast (May/June 2008). Specifically, we wanted see if we could minimize the impact on quality—as evaluated by cupping scores and green coffee moisture contents—of environmental variables during long-distance transportation and long-term warehouse storage. Some of these variables include temperature, relative humidity, and volatile chemicals such as gasolines that are sometimes loaded near coffee containers on marine transport ships.

WHAT SORT OF SCIENCE CAN BE HELPFUL TO IMPORTERS AND ROASTERS?

Perhaps unfortunately, much of the attention on coffee quality science over the past two decades has focused on the identification of single chemicals or small groups of compounds that lend this flavor or that aroma to the brewed cup. As recently as this year's SCAA 2008 annual conference in Minneapolis, when we told people we were conducting experiments on coffee quality the most common response was, "Have you identified any new chemicals?" Tremendous progress has been made since the 1950s in identifying over 300 volatile compounds in green coffee and over 800 flavor components in roasted coffee[3]. However, the reality is that we are still a long, long way from having a machine that can, in a matter of seconds or minutes, analyze a handful of green beans and deliver a cupping score similar to what you get at your table.

A good example of this is trigonelline, a compound first isolated from Arabica coffee in 1909 and studied in depth during the intervening decades[3]. Interestingly, although trigonelline is known to be a bittering agent on its own, higher levels of trigonelline in *green* Arabica correspond to a much higher *brewed* cup quality, and this is because trigonelline is broken down during roasting into numerous other chemicals[2,3]. So, scientific studies aimed at identifying specific compounds or groups of similar chemicals in green and roasted coffees, although they are interesting, are not likely to provide practical applications for roasters and importers in the immediate future.

It is the gap between objective, quantitative measurements and subjective, qualitative opinions that we are hoping to bridge with our preliminary experiments. In other words, we want to test coffees shipped and stored in different ways and turn our cupping scores into semi-quantitative evaluations of the transportation and packaging methods used so that importers and roasters can apply the best approaches and, ultimately, provide the best quality coffee to customers.

A SHORT PRIMER ON COFFEE QUALITY SCIENCE.

But what aspects of coffee quality, as it relates to storage and transportation, have already been explored scientifically? Surely someone must have done this before. Indeed, we took a great deal of inspiration from previous experimental work both in the coffee industry and in other branches of agriculture and food science. For example, in the 1970s and 1980s, some superb coffee experiments were conducted in Kenya, including a study of appropriate paints for use in coffee storage warehouses. This paint study was directed at avoiding apparently innocuous paints that would actually contaminate green coffee with undesirable volatile aroma compounds and so these "lost" experiments should actually be of great interest to importers and roasters.

One of the questions we asked was, "What about moisture content?" It is widely accepted that an initial dried green coffee moisture content of approximately 10-11% is best for good quality coffee, but where did this number come from? Is it simply trial and error? Although this number has been obtained through trial and error on the part of innumerable producers over many years, yet another coffee study from Kenya quantitatively assessed changes in cup quality over 12 months at a range of storage temperatures (10-35°C, or 50-95°F) and with a range of initial moisture contents (8.5%, 10.8%, 12.7%, and 15.5%)7. The best initial cup quality was at an initial moisture content of 10.8%, and this quality was well preserved over 6 months at storage temperatures of 10°C and 17°C. At initial moisture contents of 10.8% or higher, quality deteriorated quickly above 17°C.

This led to another question: "What about temperature?" The effects of temperature turned out to be tightly linked to those of relative humidity. An excellent experiment from a research team in Brazil assessed variations in temperature and humidity as part of their study of the effect of port storage and maritime and overland transportation on fungal contamination of green coffee[4]. This experiment showed that over one and a half months of storage and transportation, temperature varied over a 40°C range (approximate 7-47°C) and relative humidity varied over a 30% range (20-50%). This variability led to condensation forming inside the containers, the coffee bags getting wet, and ultimately to fungal contamination and the production of ochratoxin A, or OTA.
OTA is a toxin that damages kidneys and is carcinogenic[1,4] and thus in many European countries (but not in the United States) green coffee cannot be sold if it contains more than 8 μg/kg of OTA[4]. In addition, OTA is partially but not completely broken down during roasting, and the toxin itself contributes undesirable cup flavors. So, health effects aside, small amounts of fungal contamination are obviously not good for quality[6]. In summary, importers and roasters can provide better quality coffee to their customers by minimizing fluctuations in the temperature and relative humidity of the transportation and storage environments.

TYING IT ALL TOGETHER: WATER ACTIVITY.

In fact, temperature, relative humidity, green bean moisture content, fungal and toxin contamination, and even the paint you use in your warehouse are all linked through one key factor: water activity. What is water activity? Technically speaking, water activity, or aw, is defined as the ratio of the water vapor pressure in a material to the water vapor pressure of pure water at the same temperature. For example, if your green coffee is stored at 25°C, then the beans' water activity will be the ratio of their vapor pressure to that of pure water at 25°C. From a more practical perspective, aw is a measurement of the energy of the water present in a specific place at a specific time, under specific conditions. For example, the water in green coffee has very different energy during the maritime journey at 30°C and 70% RH, compared to in your warehouse at 20°C and 40% RH. This is because molecules move more and faster at higher temperatures (e.g., 30°C versus 20°C), and also because water inside a material, such as a coffee bean, will be less likely to move across the boundary containing it—such as the bean's cell walls—when there is more water beyond that boundary (e.g., higher relative humidity). Clearly numerous environmental factors determine water activity. The energy of water is important in food products such as coffee because this energy determines how easily the water moves from one place to another.

Here is a semi-technical explanation of the impact of green coffee water activity on flavor and aroma. The molecular structure of water, or H_2O, means that it has more positive charge distributed at one end (the "H2" end) and more negative charge distributed at the other end (the "O" end), much like a battery. This is the reason why you don't use a hair dryer in the bathtub: namely, water is a polar molecule with a difference of electrical charge between its two poles. This charge difference means not only that relatively large amounts of water conduct electricity, but that very small amounts of water, such as the water found in a single cell of a coffee bean, will bind to other charged substances found nearby, for example, the volatile trigonelline compound described earlier. This water binding has two implications for coffee beans, which relate to the relative humidity of the air around coffee beans. The first implication is that when the relative humidity of the air near coffee beans drops too low, then the electrical bonds between molecules in the beans are no longer strong enough to hold the water, and it leaves the bean. The second implication is that certain small, charged molecules in the coffee bean will remain bound to the water that is leaving. Some of these departing molecules will be volatile aroma and flavor components. On the other hand, when the relative humidity of the air around the beans rises too high, new water will move back into the bean, and this time the water may be bound to new and often undesirable charged, volatile aroma and flavor components. For beans at approximately 11% moisture content and in an environment with approximately 60% relative humidity, the water in the beans is in equilibrium with its environment. In other words, at 11% moisture content and 60% relative humidity, water is the least likely to leave or enter the beans, carrying volatiles with it.

Beans with a higher moisture content will tend to have higher a_w, but it is important to understand that a_w and moisture content are *not* the same. For example, two green coffees with the same moisture content may contain water with different energy depending both on the environment surrounding the bean (as described for low and high humidity above) and on the state of the beans themselves. For example, it is possible that beans that have been frozen and thawed multiple times during transcontinental shipping during winter months have experienced physical damage that reduces water binding inside the beans or has broken the cell membranes that usually contain the water. This damage could lead to a higher water activity and an *easier* exchange of water and volatiles, even if the relative humidity were closer to the ideal level of ~60%.

So the energy of the water in green coffee, or aw, is critical to preserving coffee quality, and this energy is dependent to a great extent on moisture content, relative humidity, and temperature. A properly dried green coffee has an a_w of approximately 0.55-

0.604 (recall that aw is calculated as the ratio of two vapor pressures, so the units in the ratio cancel and aw is a unit-less value). a_w between 0.60 and 0.70 promotes nonenzymatic browning reactions such as the Maillard reaction, even at room temperature, and aw above 0.70 tends to promote fungal growth, such as the fungi that produce ochratoxin A[5]. Moreover, coffee beans with a high aw will tend to exchange water and bound volatiles with the surrounding environment more easily and thus it is important to have a clean warehouse with, for example, proper paint.

TOOLS FOR IMPORTERS AND ROASTERS: HERMETIC STORAGE AND CLIMATE CONTROL.

In our previous article, we referred to the Mesoamerican Development Institute Corporation (www.mesoamerican.org) study that evaluated standard warehouse storage of green coffee, compared to hermetic (i.e., airtight) storage in GrainPro cocoons (www.grainpro.com) Café Britt in Costa Rica. The warehouse storage conditions led to large temperature and relative humidity variations over ranges of, respectively, 15-32°C (60-90°F) and 40-90%, sometimes in a matter of only a few days. After 6 months, the coffee cup score fell from 4/5 to 3/5 with a corresponding change in green bean moisture content from 11% to 13%. Remarkably, inside the cocoon the temperature and relative humidity fluctuations were only a fraction of the warehouse values: 21-23°C (70-73°F) and 55-57%. The result? Over 6 months the cup score did not change from the initial 4/5, and the bean moisture content only increased from 11% to 11.5%.

Importantly, GrainPro also makes small bags for storage and shipping of quantities as small as 10 kg. These bags can be heat and vacuum sealed or even nitrogen flushed. We are hopeful that such bags will help to offset changes in green coffee water activity by minimizing the temperature and humidity variability observed during transportation in the Brazilian study described above.

Part of our experiment has been to compare coffee shipped and stored in standard jute bags to coffee shipped in jute and transferred to GrainPro on arrival at our warehouse, or bagged in GrainPro at origin and sealed until cupping at our facility. Another component has been to compare bags stored in our warehouse to those stored in a climate controlled room where temperature and relative humidity are set at, respectively, 17°C (63°F) and 60% relative humidity.

OUR EXPERIMENTAL DESIGN.

From January 1, 2008, until April 30, 2008, we investigated 4 coffees under several conditions, which are summarized in Table 1. The primary conditions tested were jute compared to 70 kg-capacity GrainPro SuperGrainbags™ (GrainPro Inc., Concord, MA) for shipping and storage of green coffee, and the use of a standard warehouse compared to a climate controlled room for long term storage of green coffee. We hypothesized that, compared to coffees shipped and/or stored in jute bags and warehouse conditions, coffees shipped and/or stored in GrainPro bags and in climate control conditions would have moisture contents in the desired range (10-11%) and better cup scores.

The GrainPro bag is formed from two plastic layers filled with a nitrogen layer, with an overall thickness of three thousandths of an inch (0.003 mm). Compared to Mylar, these reusable and recyclable bags are 4 times less permeable to water vapor and 2 times less permeable to oxygen, and they are also resistant to UV light.

Our climate controlled test room was set at 63°F (17°C) and 60% relative humidity.

We continuously monitored temperature (°F) and relative humidity (%) in both storage areas using Onset HOBO U10-003 Dataloggers (Onset Computer Corporation, Pocasset, MA). The ongoing changes in temperature and relative humidity in the two storage areas are shown in Figure 1 (warehouse) and Figure 2 (climate control), where the red traces reflect the ongoing changes in relative humidity and the black traces represent the ongoing changes in temperature. These data are summarized in Table 1 as target temperature and humidity, mean plus or minus standard deviation (an estimate of the overall variability), total range, minimum, and maximum. Note that, overall, the temperature variability in the climate control room was approximately identical to that in the warehouse. In contrast, the relative humidity in the climate control room was 22°F higher and 3.5 times less variable, on average, compared to warehouse conditions.

After 4 months, we sampled each of these coffees. Moisture contents were measured with a Sinar AP6060 Moisture Analyzer (CSC Scientific Corp. Inc., Fairfax, VA), the beans were roasted in 100 g samples in a Probat BRZ 4 sample roaster (Probat Burns Inc., Memphis, TN), and the roast consistency was double-checked using an Agtron M-Basic/II Coffee Roast Analyzer (Agtron Inc., Reno, NV). Samples were cupped in two separate sessions by a panel of either 7 expert cuppers using a Cup of Excellence scoring form (El Salvador, Ethiopia), or 4 expert cuppers using our in-house scoring form (Costa Rica, Brazil). Cup scores were analyzed for statistical significance using a *T* test when comparing 2 conditions (Brazil, Costa Rica, El Salvador) and using an ANOVA followed by a Tukey post-hoc test when comparing 3 conditions (Ethiopia). Differences were accepted as statistically significant at $P < 0.05$ (i.e., if the P value was less than 0.05 then the conditions were considered different from each other by a statistically significant margin).

OUR EXPERIMENTAL RESULTS.

The results of our analyses are summarized in Table 1. Both the Brazil and El Salvador coffees (Table 3-1 and 3-3) were shipped in Mylar vacuum packs, which were opened upon arrival and the coffees repackaged into either jute or GrainPro. For coffees from both origins, storage from January through April in GrainPro, compared to jute, resulted in better cup quality scores. For the El Salvador, this difference in cup score was statistically significant. Interestingly, for the Brazil, this difference in cup score was not statistically significant, but the GrainPro storage, compared to jute, also preserved moisture content at the desired level (10-11%).

Thus overall it appears that under standard warehouse conditions, long-term storage in GrainPro, compared to jute, may preserve coffee much better, leading to moisture content in the desired range and ultimately to better cup scores.

Comparing the Costa Rica coffees (Table 3-2, jute shipping and storage versus GrainPro shipping and storage) revealed that the moisture content of the coffee shipped *and* stored in GrainPro (13.9%) was much higher than that of the coffee shipped and stored in jute (10.3%). Importantly, a small, representative sample of this coffee was air freighted to us in vacuum-packed Mylar immediately before the bulk shipment was sent via standard marine routes, and this well-preserved sample had a moisture content of 13.9%. Consistent with the Café Britt study in Costa Rica, this result suggests that GrainPro preserves coffee extremely well beginning at origin, and this preservation can even include the maintenance of undesirable green bean properties, such as excessive moisture content. Interestingly, compared to the coffee from the jute bag, and despite its high moisture content, the coffee from the GrainPro bag received a significantly higher cup score, although the cuppers noted that it tasted a bit "green." Thus, despite the high moisture content, the cup quality was better preserved by GrainPro and the only issue with this coffee appeared to be that it needed to be better dried at origin. In fact, it seems likely that the relatively large fluctuations in relative humidity in our warehouse, and that are also known to occur during maritime shipping[4], led to migration of moisture out of and into the unprotected, jute-bagged beans. Ultimately this would lead to the exchange of desirable volatiles for undesirable volatiles and deterioration in aroma and flavor, compared to the coffee in GrainPro bags.

The Ethiopian coffees (Table 3-4) were all shipped in jute bags. On arrival one of these bags was stored as-is in the warehouse. Another bag was stored in climate control. The third bag was rebagged into GrainPro for storage in the warehouse. Our statistical analyses of these three conditions revealed that *each* cup score was different from the two other scores. The best quality coffee came from the jute bag stored in climate control, and this coffee had an almost ideal moisture content of 10.2%. The next best quality coffee was from the GrainPro bag, with a moisture content of 9.7%. Finally, the jute bag stored in the warehouse yielded the lowest quality of the three Ethiopian bags, and the moisture content of this coffee was 12.4%. Thus, overall, the results of the Ethiopian coffee comparison suggests that cup quality is better preserved after long-term storage with either climate control or GrainPro, and this preserved moisture content is also associated with better maintenance of cup aroma and flavor.

A FEW RECOMMENDATIONS.

We set our climate control room at a temperature of approximately 63°F and a relative humidity of approximately 60%. As it turned out, our average warehouse temperature and its variability were very close to the climate control conditions, and so we cannot speculate as to the effect of temperature in our experiment. However, based on these informal experiments, it appears that using hermetically sealed bags for transportation from origin, and using either hermetically sealed bags or climate controlled environments for long term warehouse storage, are both effective methods for preserving green coffee quality. Thus, keeping in mind that these data are preliminary, we would recommend these solutions to importers and roasters who want to improve their product. Currently we are investigating the effect of freezing and thawing on green coffee quality. We are also bringing in jute and hermetically-sealed bags from Guatemala that contain data loggers so that we can monitor changes in temperature and humidity in sealed and non-sealed bags during maritime shipping in addition to long-term storage. In the future, we hope to measure water activity directly to see how changes in water activity of green beans during long-term storage affect cup quality. Finally, we encourage other importers and roasters to perform their own informal experiments in order to yield the best possible coffee quality.

*NOTE: A. MILLER, FOR THE KEEPING: STORING & PRESERVING GREEN COFFEE, PART 1 OF 2. ROAST MAGAZINE: May/June: 54-65.

REFERENCES

1. Bucheli P, Meyer I, Pittet A, Vuataz G, Viani R. 1998. Industrial storage of green Robusta coffee under tropical conditions and its impact on raw material quality and ochratoxin A content. J Agric Food Chem 46: 655-665.

2. Farah A, Monteiro M, Calado V, Franca A, Trugo LC. 2005. Correlation between cup quality and chemical attributes of Brazilian coffee. Food Chem 98: 373-380.

3. Flament I, Bessière-Thomas Y. 2002. Coffee Flavour Chemistry. Chichester: John Wiley & Sons, Ltd.

4. Palacios-Cabrera HA, Menezes HC, Imanaka BT, Canepa F, Teixeira AA, Carvalhaes N, Santi D, Leme PTZ, Yotsuyanagi K, Taniwaki MH. 2007. Effect of temperature and relative humidity during transportation on green coffee bean moisture content and ochratoxin A production. J Food Prot 70: 164-171.

5. Schwimmer S. 1980. Influence of water activity on enzyme reactivity and stability. Food Technol 14: 64-65.

6. van der Stegen GHD, Essens PJM, van der Lijn J. 2001. Effect of roasting conditions on reduction of ochratoxin A in coffee. J Agric Food Chem 49: 4713-4715.

7. Stirling H. 1980. Storage research on Kenya Arabica coffee. ASIC Proceedings 9: 189-200.

8. Wootton AE, Verkaik A. 1970. The selection of paints for coffee tanks and channels. Kenya Coffee 35: 218.

Table 1. Summary of experimental transportation and storage conditions tested using green coffee from Brasil, Costa Rica, El Salvador, and Ethiopia.

	Origin	Coffee	Shipping container	Storage container	Storage location
	Brazil A	Natural Fazenda Pedra Preta	Mylar	Jute	Warehouse
1	Brazil B	Natural Fazenda Pedra Preta	Mylar	GrainPro	Warehouse
	Costa Rica A	Tres Rios La Dama SHB	Jute	Jute	Warehouse
2	Costa Rica B	Tres Rios La Dama SHB	GrainPro	GrainPro	Climate Ctrl.
	El Salvador A	La Montana	Mylar	Jute	Warehouse
3	El Salvador B	La Montana	Mylar	GrainPro	Warehouse
	Ethiopia A	Yergacheffe van Wondo	Jute	Jute	Warehouse
4	Ethiopia B	Yergacheffe van Wondo	Jute	GrainPro	Warehouse
	Ethiopia C	Yergacheffe van Wondo	Jute	Jute	Climate Ctrl.

Table 2. Temperature and relative humidity of warehouse (WH) and climate control (CC) storage areas from Jan. 1, 2008 through April 30, 2008 (SD, standard deviation).

	Target	Mean +/-	Range	Minimum	Maximum
WH Temp (°F)	—	61.9 ± 1.3	5.2	59.5	64.7
CC Temp (°F)	62.6	63.0 ± 1.4	5.2	60.7	65.9
WH RH (%)	—	38.8 ± 4.2	14.4	33.2	47.6
CC RH (%)	60.0	61.0 ± 1.2	4.3	58.9	63.2

Table 3. Moisture content (MC) and cup scores of Brazil, Costa Rica, El Salvador, and Ethiopia coffees after shipping or storage in Mylar (My), jute (Ju), or GrainPro (GP) bags, and after 4 months of storage in warehouse (WH) or climate control (CC) conditions (n/m: not measured).

	Coffee and conditions	MC (%)	Cup score (mean +/-)	Statistical test	P Value	Significant difference?
	Brazil A (My-Ju/WH)	9.6	83.0 ± 3.9	*T* test	0.2121	N
1	Brazil B (My-GP/WH	10.6	84.7 ± 2.2			
	Costa Rica A (Ju-Ju/WH)	10.3	81.3 ± 1.3	*T* Test	0.0211	Y
2	Costa Rica B (GP-GP/CC)	13.9	83.6 ± 0.6			
	El Salvador A (My-Ju/WH)	n/m	84.2 ± 3.7	*T* Test	0.0111	Y
3	El Salvador B (My-GP/WH	n/m	89.3 ± 2.7			
	Ethiopia A (Ju-Ju/WH)	12.4	86.7 ± 2.6	ANOVA		Y-every
4	Ethiopia B (Ju/GP/WH)	9.7	90.4 ± 2.2	with Tukey	0.0001	compar.
	Ethiopia C (Ju-Ju/CC)	10.2	93.6 ± 3.4	post-hoc		different

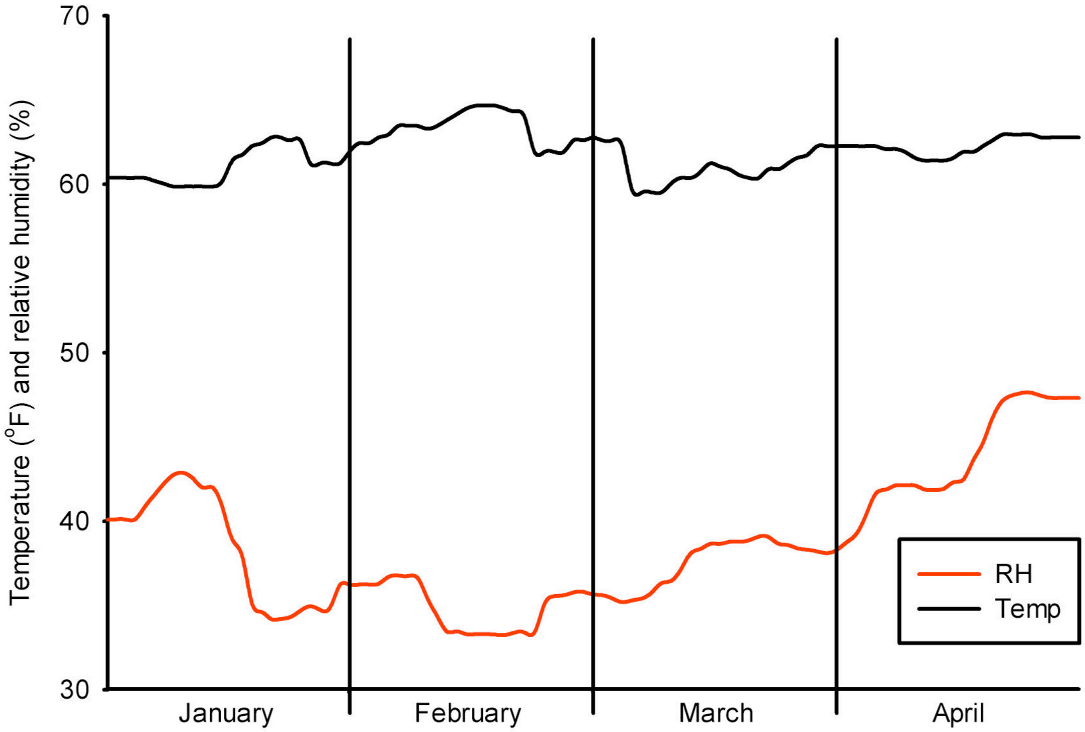

Figure 1. Changes in temperature and relative humidity under standard warehouse conditions from January 1 through April 30, 2008.

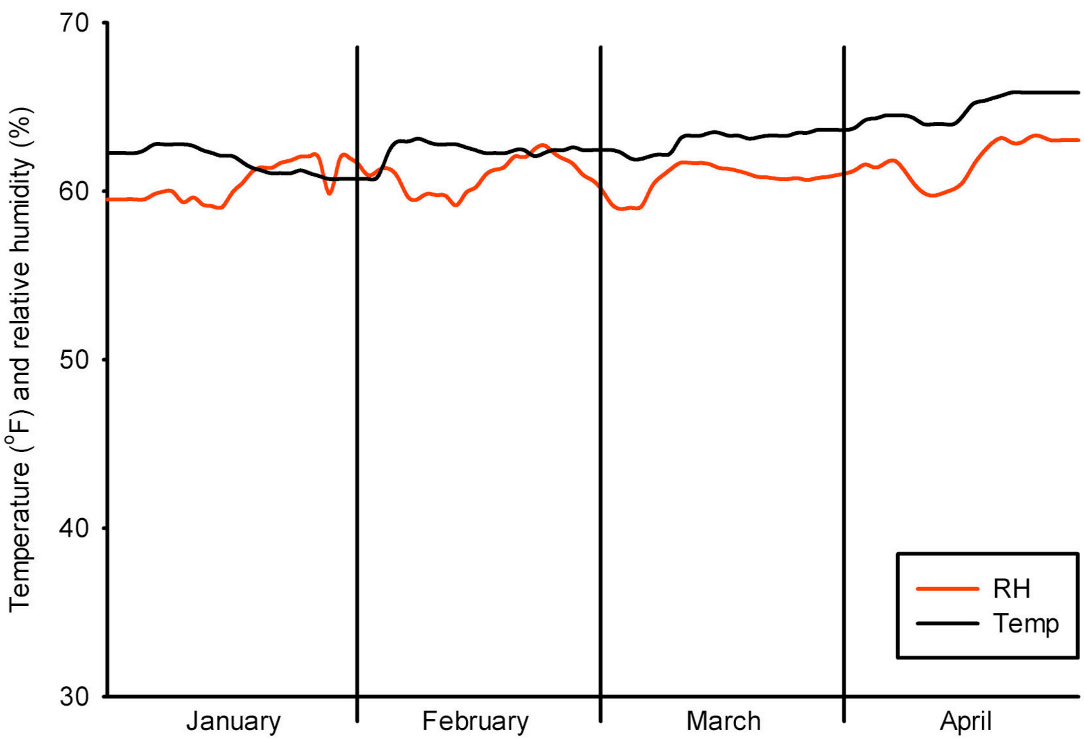

Figure 2. Changes in temperature and relative humidity in climate control storage room set at 63°F and 60% relative humidity, from January 1 through April 30, 2008.