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Preservation of roasted and ground coffee during storage Part 1: Moisture content and repose angle

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Key words:
Coffea arabica
Coffea canephora
post-harvest

ABSTRACT

The present study evaluates the influence of the level of roasting and the grind size on the moisture content and repose angle of coffee during storage. Raw coffee beans (*Coffea canephora* and *Coffea arabica*), hulled and dried, were roasted to two different levels: medium light (SCAA#65) and moderately dark (SCAA#45). The beans were then ground into three different grind sizes: fine (0.59 mm), medium (0.84 mm) and coarse (1.19 mm). An additional coffee lot was kept whole. Following grinding, samples were stored at two different temperatures (10 and 30 °C) and analyzed after five different storage durations (0, 30, 60, 120 and 180 days). The moderately dark roast was found to have a lower moisture content. Finely ground samples had higher angles of repose. It is concluded that the grind size, level of roasting and duration of storage significantly affect the moisture content and angle of repose of coffee.

Palavras-chave:
Coffea arabica
Coffea canephora
pós-colheita

Conservação de café torrado e moído durante o armazenamento. Parte 1: Teor de água e ângulo de repouso

RESUMO

Objetivou-se, com este trabalho, avaliar a influência dos níveis de torrefação e moagem sobre o teor de água e ângulo de repouso de café, durante o armazenamento. Foram utilizados grãos de café cru (*Coffea canephora* e *Coffea arabica*), descascados e secos e torrados em dois níveis: média clara (SCAA#65) e moderadamente escura (SCAA#45). Os grãos foram então moídos em três granulometrias: fina (0,59 mm), média (0,84 mm) e grossa (1,19 mm) além do lote de café inteiro. Realizada a moagem as amostras foram armazenadas em duas temperaturas (10 e 30 °C) e analisadas em cinco tempos distintos (0, 30, 60, 120 e 180 dias). A torrefação a nível moderadamente escuro proporcionou menores valores de teor de água. Obtiveram-se, com amostras mais finas, maiores valores de ângulo de repouso. Conclui-se que a granulometria, o nível de torrefação e o tempo de armazenamento afetaram significativamente o teor de água e o ângulo de repouso do café.

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Introduction

Water is present in practically all foodstuffs and it has an important role in a great amount of chemical reactions. The preservation of whole and ground roasted coffees is necessary for its commercialization, both in the internal Brazilian market and in the external market. Different factors can influence the preservation of coffee and, consequently, its final quality, including cultivation, harvest and post-harvest processing (roasting, grinding and storage).

Roast level has been reported to determine the final quality of the beverage (Melo, 2004), and significant changes to coffee's physical properties have been observed to occur during roasting (Mwithiga & Jindal, 2003). Grinding results in powdery products that can have different particle sizes according to the market's needs (Schmidt et al., 2008) and affect the physical properties of coffee (Geldart et al., 2009; Lopes Neto et al., 2009; Langroudi et al., 2010). Storage of roasted and ground coffee is not recommended because grinding promotes cell breakage and therefore enables the loss of molecular components, negatively affecting quality. Furthermore, the caking effect causes difficulties regarding the transport of this product. However, coffee roasted and ground may need to be stored due to a lack of transportation, prices that make immediate commercialization impossible and the need to formulate coffee blends. In addition, bulk storage can be a great advantage because it enables the mechanization of coffee processing, which substantially decreases the amount of labor required compared to traditional storage methods (Oliveira et al., 2014).

Thus, the aim of the present study was to evaluate the alterations of water content and angle of repose of coffee roasted to different levels, ground to different sizes, and stored at different temperatures.

Material and Methods

Raw coffee beans (*Coffea canephora* and *Coffea arabica*), hulled and dried, were acquired from the regional markets of Zona da Mata, Minas Gerais, Brazil. The coffee beans were sorted to eliminate deteriorated, damaged and bored beans and to obtain a homogeneous lot with minimal defects. The initial water content of the coffee beans was determined through gravimetry using a forced-air circulation oven at 105 ± 1 °C for 24 h (Brasil, 2009) in triplicate. The average initial water content was 12.61% (dry basis). Following sorting, coffee beans from both species were roasted using a direct-flame LPG gas roaster with a rotating cylinder at 45 rpm with a 350-g raw coffee roasting capacity. The different roast levels were identified through monitoring and comparison of sample colors with the Agtron color reference standards with the assistance of a trained professional. Two roast levels were obtained: medium light (ML) and moderately dark (MD), corresponding to the Agtron standards SCAA#65 and SCAA#45, respectively (Figure 1). To guarantee the uniformity of the roast, a portable infrared thermometer (Mult-Time) with a temperature range from -50 to 500 °C, 1 s response time and 0.1 °C resolution was used.

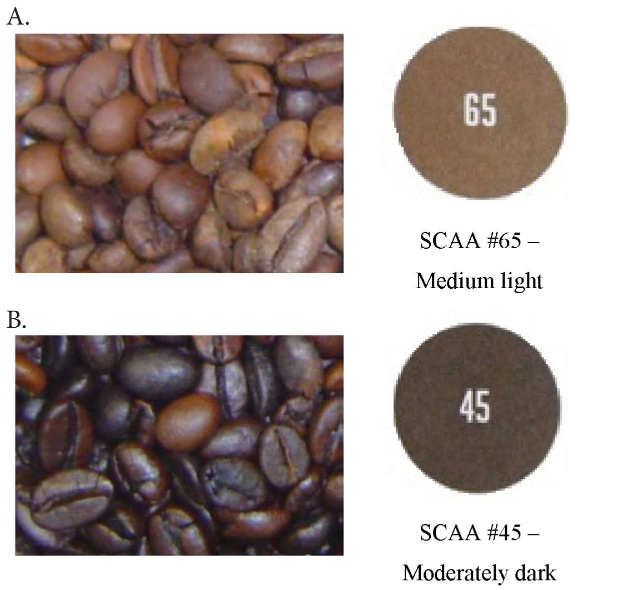


Figure 1. Roasting degrees employed: medium light - ML (A) and moderately dark - MD (B)

ML and MD roasted coffee beans lost an average of 15.85 and 18.74 g when the roaster reached 285 °C, respectively (Vargas-Elías, 2011).

When each roast level was reached, the beans were removed from the roaster and immediately cooled at ambient temperature. Following roasting, the coffee beans were ground with a mill (Mahlkönig) into three different grind sizes according to ABIC (2013) (Table 1): fine (0.59 mm), medium (0.84 mm) and coarse (1.19 mm). An additional lot was kept whole.

The processed samples were then placed in polypropylene bags and stored in B.O.D. chambers at two different temperatures (10 and 30 °C) for six months. Water content of the stored samples was analyzed at five different times during storage (0, 30, 60, 120 and 180 days). The water content of roasted, whole and ground coffee was determined through gravimetry using a forced air circulation oven at 105 ± 1 °C for 24 h (Brasil, 2009). Each sample was measured in triplicate, and the average of the three measurements was used. The angle of repose was measured according to Silva et al. (2006). Each sample was deposited in a cylindrical container (20 cm in diameter) with a graduated rod at its center, from a reception funnel at a height of 0.60 m. The height of the slope formed by the sample in the container was measured. The angle of repose was calculated as the tangent of the triangle formed by the base of the sample and the height of the slope. Each sample was analyzed in triplicate, and the average of the three measurements was used. The experimental design

Table 1. Classification based on the percentage retention in sieve numbers 12, 16, 20, 30 and at the sieve bottom pan, with 10 min agitation and the rheostat set at position 5

Grinding	% retention			Tolerance % passing through sieve 30	
	Sieve 12 and 16	Sieve 20 and 30	Sieve bottom pan	Minimum	Maximum
Coarse	33	55	12	9	15
Medium	7	73	20	16	24
Fine	0	90	30	25	40

Source: ABIC (2013)

was completely randomized, with the number of replicates varying depending on the physical property measured. Two experiments were performed: one using *Coffea arabica* L. and another using *Coffea canephora* Pierre. ANOVA, followed by Tukey's test, was performed for both experiments, with significance at $p < 0.05$. All statistical analyses were performed using SAEG® software. For the comparison of different storage times, a regression analysis using average values was performed. The best-fit models were selected based on the highest coefficient of determination (R^2) and the significance of the parameters.

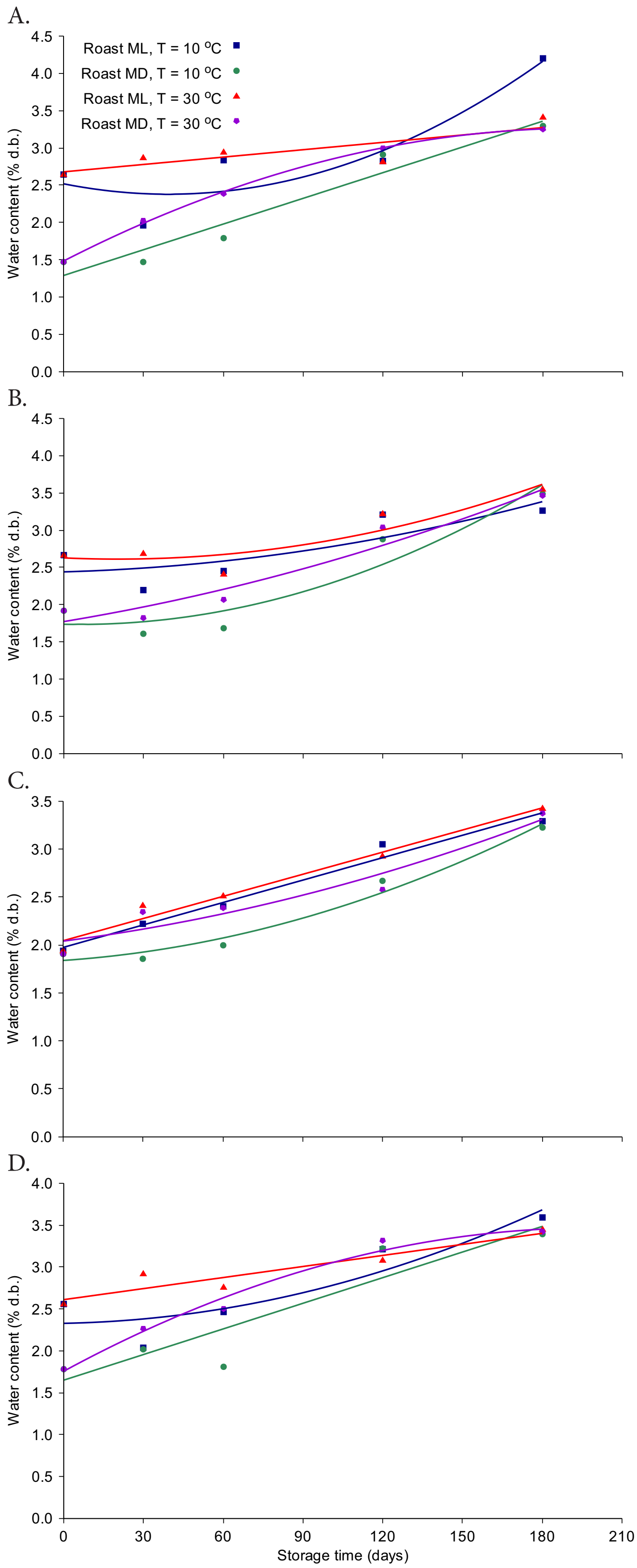
Results and Discussion

Storage time alone and its interaction with variable roast levels and grind sizes significantly affected the water content of all samples at the two temperatures tested. This effect occurred independently from the coffee species and the storage temperatures tested. Roasted whole coffee had greater water content variation during storage, regardless of the coffee species. Fine, medium and coarse grinds showed greater increases in water content linearity during storage.

Figures 2 and 3 show the values of water content of roasted and ground coffee, as a function of storage time, respectively for *Coffea arabica* and *Coffea canephora* (Robusta).

According to Illy & Viani (1995), values of water content ranging between 1.00 and 3.70% (d.b.) indicate that moisture is aggregated within the product at monolayer level. This trend occurred for Arabica samples, with the exception of whole coffee beans roasted at ML level and stored at 10 °C, after 180 days. For Robusta coffee, this fact occurred in all samples, except for coffee ground fine with roast MD, stored at 30 °C after 120 days of storage. Thus, water molecules at these water content values are strongly adsorbed at specific sites within the product, and water activity is considered to be low (Illy & Viani, 1995). Regardless of the size of grounds or the coffee species tested, water content increased during storage, reaching between 3.5 and 4.0% (dry basis) at 180 days. These values are in accordance with the legal limits (up to 5.0% wet basis, or 5.26% dry basis) (Brasil, 2010). This was expected because roasted coffee is hygroscopic, i.e., it can absorb water from a medium. The low initial water content of coffee induces moisture adsorption, increasing its water content over time. The same trend was reported by Oliveira et al. (2015) working with green coffee beans.

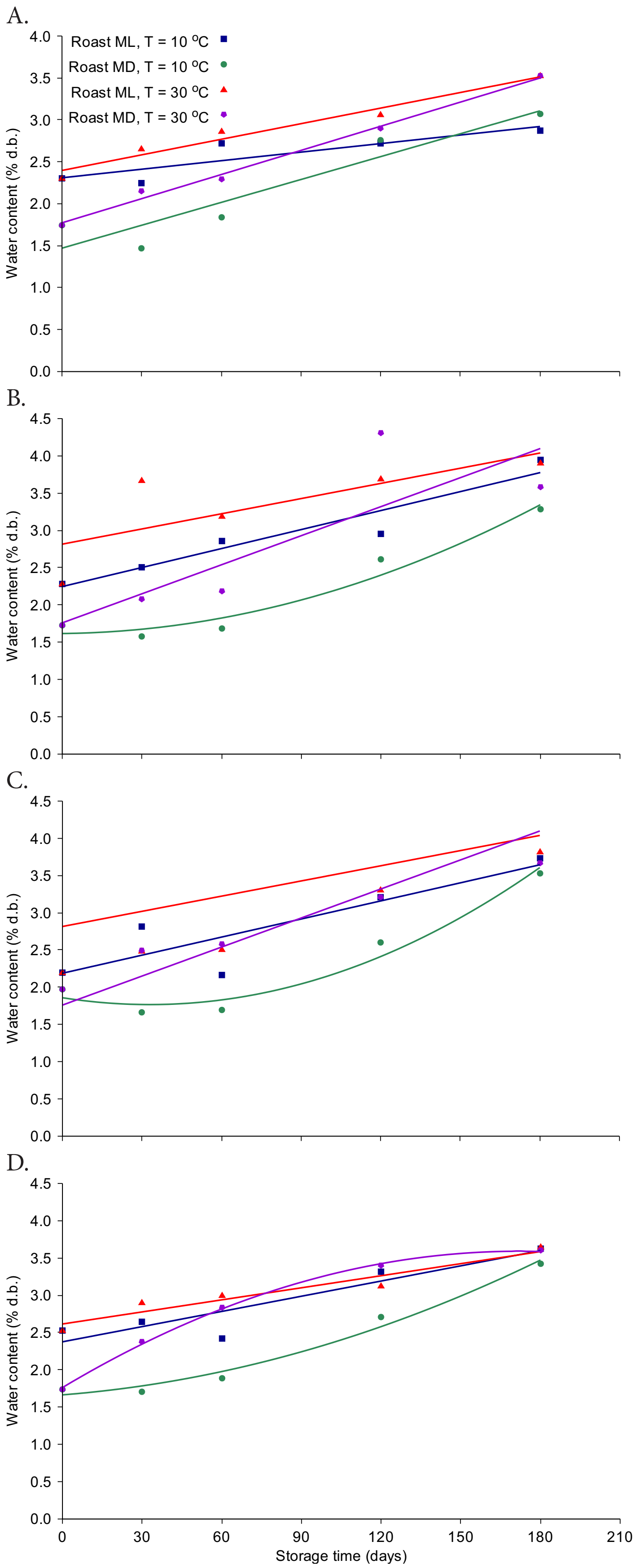
MD roasted coffee showed lower water contents compared with ML roasted coffee. The longer roast time (MD roast) resulted in greater weight loss due to water evaporation. This result is consistent with previous reports (Baggenstoss et al., 2008; Schmidt et al., 2008; Bicho et al., 2012). However, the difference of water content due to roasting degree becomes lower during storage, with the tendency to equalize after 180 days. This trend indicates that roasting level did not affect the hygroscopicity of the coffee samples, because the capacity of coffee to gain moisture from the environment is practically the same after 180 days of storage. Roasted whole and ground coffees stored at 10 °C exhibited lower water contents, which tended to equilibrate after 150 days of storage. This result is



ML - Medium light; MD - Moderately dark

Figure 2. Mean water content of roasted Arabica coffee during storage at 10 and 30 °C. Coffee beans were whole (A) or ground, with fine (B), medium (C) or coarse (D) grind sizes

consistent with Fernandes et al. (2006), who analyzed the chemical composition of roasted and ground coffees during 210 days of storage at 5 and 25 °C and observed lower water content in coffee stored at 5 °C. This trend is expected, since higher



ML - Medium light; MD - Moderately dark

Figure 3. Mean water content of roasted Robusta coffee during storage at 10 and 30 ºC. Coffee beans were whole (A) or ground, with fine (B), medium (C) or coarse (D) grind sizes

storage temperatures leads to a higher level of excitation of water molecules and availability of sorption sites in the product, incrementing the moisture retrieve from the environment (Corrêa et al., 2010).

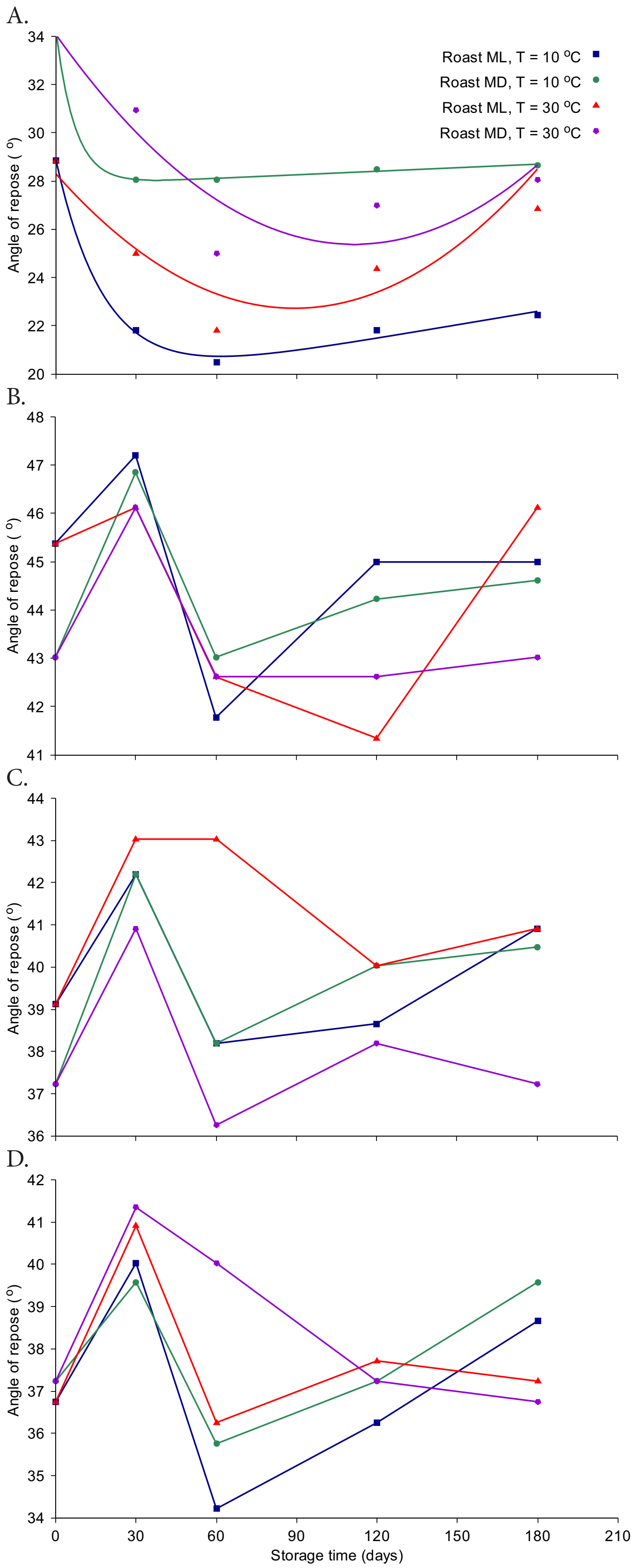
Angle of repose is useful in order to acquire information regarding solid flowability. According to Shittu & Lawal (2007), during powder reconstitution, water molecules that hydrate the product's surface tend to reduce cohesivity between particles, allowing a rapid water penetration; thus, powders that possess high angles of repose, have higher difficulty to incorporate water. All factors tested (roast level, grind size and storage time), and the interactions between them, significantly influenced the angle of repose (α). This was independent of the coffee species and storage temperature tested. The behavior of the angle of repose during storage for *Coffea arabica* and *Coffea canephora* is presented in Figures 4 and 5, respectively.

Different α behavior was observed for the roasted whole and ground coffees, regardless of the species (Figures 3 and 4). The angle increased from the time of harvest until 30 days of storage for ground coffees, but decreased from the time of harvest in whole coffee. For all analyzed samples, α tended to increase during storage.

The behavior observed during the first 30 days is explained by the integrity of roasted coffee cells. Without grinding, coffee beans are better able to preserve their constituents and water content due to the physical barrier presented by intact cells or cells with a low degree of rupture. Grinding breaks that barrier, increasing the speed of exchange between the product and the medium, resulting in agglomeration due to water absorption. This agglomeration occurs abruptly as storage begins due to the low water content following roasting, making the product more hygroscopic and resulting in higher moisture absorption during this phase. This absorption leads to agglomeration, decreasing coffee flowability and increasing α. This effect is indicated by the α values for whole (between 20 and 34º) and ground coffees (between 32 and 48º). Over time, the water molecules entering the whole coffee beans and the moisture adsorbed by the ground coffee results in the gradual increase of the angle of repose, and the samples tend to equilibrate. This effect is expected because longer exposure of the product to the environment allows constant interaction, resulting in increasing water content that is dependent on the ambient relative humidity. Teunou & Fitzpatrick (2000) reported that powdery products become more cohesive over time, as the product compacts due to its own weight and to moisture absorption, which is consistent with the present results.

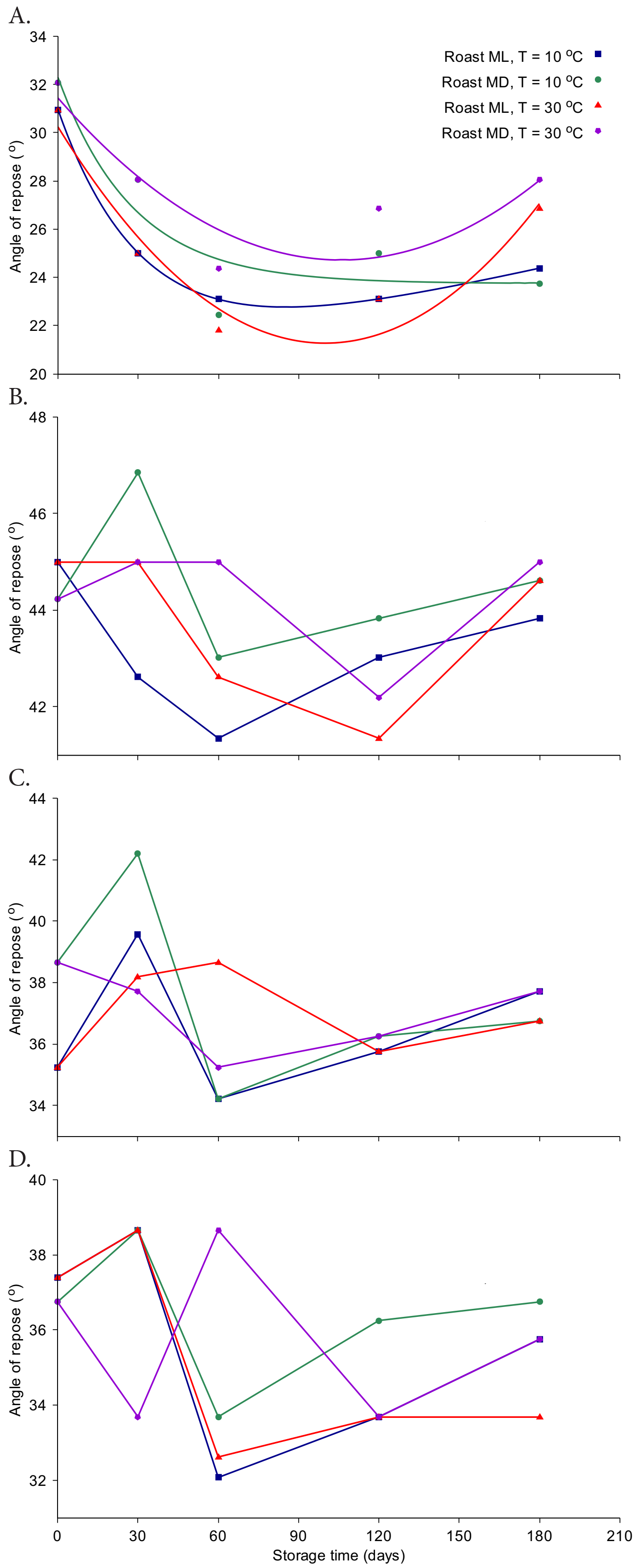
The size of grounds played an important part on the variation of α. The coarser the coffee was, the lower the angle of repose (Figures 2 and 3, A, B and C). Geldart et al. (2009) reported that the higher the grind size is, the lower the number of particles per unit of weight, thus decreasing the cohesive forces in the product. This loss of cohesion results in the formation of flatter slopes, i.e., with lower angles of repose. Lower angles of repose have a direct impact on handling, i.e. over the amount of product to be transported, such as in belt conveyors, leading to a higher cost per mass unit transported. During storage, angle of repose also plays an important role in the operation cost for filling up silos (higher angle of repose costs more due to higher number of operations to flatten the grain mass surface) and total capacity to store.

In general, the samples with higher roast levels (MD) exhibited higher α during storage (Figures 2A and 3A). Higher



ML - Medium light; MD - Moderately dark

Figure 4. Mean angle of repose of roasted Arabica coffee during storage at 10 and 30 °C. Coffee beans were whole (A) or ground, with fine (B), medium (C) or coarse (D) grind sizes



ML - Medium light; MD - Moderately dark

Figure 5. Mean angle of repose of roasted Robusta coffee during storage at 10 and 30 °C. Coffee beans were whole (A) or ground, with fine (B), medium (C) or coarse (D) grind size

roast levels result in increased friability of the product's particles, i.e., they become more likely to crumble, forming smaller particles (Medeiros & Lannes, 2010). The α of ground samples varied randomly during storage. Samples with higher roasting levels, and consequently lower water contents, were expected to show lower angles of repose because these properties are directly correlated. However, the hygroscopicity of the ground samples may have overshadowed the importance of the roast level, resulting in this random behavior. The storage temperatures tested in the present study allowed the coffee to maintain the observed levels of α, especially in the whole coffee bean samples. In the ground samples, the effect of temperature was masked by the grind size because sudden variations of the angle of repose in different samples stored at 10 °C were observed. It was not possible to fit equations to the variation of α in ground samples during the initial 30 days of storage. The regression equations fitted to the angle of repose observed for whole coffee are presented in Table 2.

Table 2. Regression equations fitted to the variation of the angle of repose (α) over storage time (t) and respective coefficients of determination (R^2) of whole coffee beans of Arabica and Robusta coffees with two different roast levels (ML - medium light; MD - moderately dark) and stored at two different temperatures

R	T (°C)	Equation	R^2
		Arabica coffee	
ML	10	$\alpha = 19.3221^{**} + 9.6365^{***} \exp(-0.0539t) + 0.0187t$	0.9956
	30	$\alpha = 28.2988^{*} - 0.1249^{***}t + 0.0007^{***}t$	0.8308
MD	10	$\alpha = 27.8212^{*} + 6.3946^{**} \exp(-0.1379t) + 0.0049t$	0.9996
	30	$\alpha = 34.0717^{*} - 0.1560^{***}t + 0.0007t^2$	0.8335
		Robusta coffee	
ML	10	$\alpha = 19.8020^{*} + 11.1610^{*} \exp(-0.0306^{*}t) + 0.0252^{*}t$	0.9999
	30	$\alpha = 30.2446^{*} - 0.1797^{**}t + 0.0009^{***}t^2$	0.9254
MD	10	$\alpha = 23.7452^{*} + 8.5520^{***} \exp(-0.0356t)$	0.8562
	30	$\alpha = 31.4433^{*} - 0.1270^{***}t + 0.0006t^2$	0.7870

*, **, and *** Significant at $p < 0.01$, < 0.05 and < 0.1, respectively, according to t-test; R - Roasting

Conclusions

1. Grind size significantly affected the water content of coffee, regardless of the coffee species and roast level.
2. The roast level was indirectly and significantly related to the water content of coffee, with the water content decreasing with increasing roast levels.
3. The water content of roasted coffee, whole and ground, increased during storage, regardless of the storage temperature, indicating that roasted coffee is hygroscopic.
4. The angle of repose of roasted coffee, whole and ground, decreased with increased grind sizes and at lower roast levels.

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