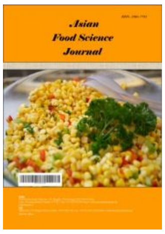

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Effect of Particle Size on Color of Ground Coffee

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Introduction: Particle size is one of the main variables that influence coffee brewing process and also most obvious to the consumers. The aim of this study was to evaluate the effect of different particle sizes on the color of ground coffee.
Methods: A laser diffraction analyzer was used to determine the particle size distribution of the 14 dry ground coffee samples. The particle size distribution of the roasted ground coffee samples that underwent grinding at different time periods was based on volume distribution. Color measurements of all coffee samples were made using a portable CR-400 tristimulus colorimeter and Spectra-Match software, set to L^*, a^*, b^* mode. Color measurements were recorded for two replicates of each sample.
Results: Coffee samples ground for short times of 30s, 20s and 10s, were observed to have coarser particles than those that underwent longer grinding times. The 20s and 30s grinding times did not exhibit any significant differences for the D50 and D90 particle size distributions. There was no significant difference in D50 and D90 values for Colombian 1.3, Leyenda and Tarrazu brands. It was observed that lightness (L^*) as well as a^* and b^* were highly significantly different between the different coffee samples with $P < 0.0001$. The coffee samples that underwent grinding for 60s had the highest L^*, a^* and b^* values of 30.72, +1.31 and +1.39 respectively. Colombian 1.3 coffee brand had the lowest L^* and a^* values of 29.8 and +0.67 respectively, with brand 1820a having the lowest b* value of +0.39.
Conclusion: The results of this study show that there was no significant effect of particle size

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distribution of coffee samples on color of the ground coffee particles. *L**, *a** and *b** values decreased during roasting, due to the darkening of the beans resulting from sugar caramelization and Maillard reactions.

Keywords: Coffee; particle size distribution; grinding; color.

1. INTRODUCTION

Particle size is one of the main variables that influence coffee brewing process and also most obvious to the consumers. Brewing coffee involves grinding roasted beans and then passing hot water over the coffee granules to extract flavor, caffeine, and other volatile compounds [1]. The final particle size of coffee grounds is determined by the time spent in the grinder. Small particle size distribution increases the surface area per unit volume than larger particles. This increase in surface area increases the rate of flavor extraction [2]. Therefore, a balance between too fine and too coarse coffee grind should be maintained so as to prevent production of very strong bitter flavor and very weak flavors respectively. Coffee grade that is too fine could decrease extraction, yielding low volume of over extracted coffee due to agglomeration and insufficient wetting of coffee particles [3].

Whereas, coffee grade with coarse particles decreases extraction, yielding under extracted coffee, due to the small volume specific surface area which is not able to retain water and allow coffee compounds to solubilize and emulsify [4-6]. Particle size is a key factor in coffee quality assurance hence the need to understand its association of desired flavor and particle size. Hence, grinding process of coffee should be empirically optimized from the start of coffee production. In order to obtain high quality coffee brew, optimization of particle size and brewing method should be ensured so as to allow exposure of the maximum surface area to the action of water [3].

However, grinding process of roasted coffee beans leads to loss of pleasant aromas of fresh brewed coffee. Fresh and pleasant aromas are highly volatile and unstable compounds hence easily released during grinding and also storage [1,7]. Grinding of coffee beans ruptures the coffee bean tissues and cells thereby accelerating the release of carbon dioxide (CO_2) gas and volatile aroma; but also enables easy extraction of the remaining aromas by absorbing moisture from air [3].

Grinding of coffee beans is influenced by factors such as the variability of coffee beans (coffee bean variety), moisture content, and the degree of roasting. The coffee varieties vary from different geographical locations, differences in processing methods (wet or dry processing) and aging before roasting leading to heterogeneity in the hardness of coffee beans and final aroma profile [3,8,9]. Coffee with high moisture content was observed to exhibit coarser particles upon grinding, and equilibration time prior to grinding was needed for the high moisture content coffee to improve grinding results [10]. During the roasting process, there is considerable increase in size of coffee beans and brittleness due to gas production [11]. This leads to hardening and brittleness of dark-roasted coffee beans than lighter roasted beans hence breakage into finer coffee grinds [12]. It should also be noted that temperature control during grinding is one of the main factors that can affect the quality of final coffee powder [13].

Espresso coffee requires fine grinds and exhibits a multiphase system, hence need for proper control of grinding step in order to achieve proper brewing and produce a highly flavored coffee brew [12,14]. A literature search did not yield many studies on the influence of grinding on the coffee extraction process. A study on effect of grinding on chemical and sensorial characteristics of espresso coffee showed that extraction and concentration yields were seen to inversely increase with particle size [3]. Influence of particle size of ground coffee on caffeine extraction has been studied by [15,16]. Studies have claimed that at small particle size of ground coffee, the extraction of soluble and volatile compounds is highest [17]. Also, studies were undertaken to investigate the effect of particle size distribution of ground coffees, percolation time, and extraction properties on an espresso coffee machine [10]. Most of the studies referenced claimed that there was a more sufficient extraction process when small particles of coffee were used due to an increase the surface exposed to water. Studies on the influence of particle size of ground coffee on sensory characteristics were not available. Thus, the current study aimed to evaluate the effect of different particle sizes on the color of ground coffee.

2. MATERIALS AND METHODS

2.1 Coffee Samples

Samples of coffee ground for different times (10s, 20s, 30s, 40s, 50s, 60s) and eight different coffee brands (Antiqua, Colombian 1.3, Leyenda, Tarrazu, Sanchez Classic, 1820a, 1820b and Najjar) were used in this study.

2.2 Determination of Particle Size Distribution

A laser diffraction analyzer was used to determine the particle size distribution of the 14 dry ground coffee samples. The Mastersizer 3000 (particle size range from 0.01 to 3500 µm) located at the Department of Food Science and Technology, Food Engineering Laboratory, University of Nebraska-Lincoln, USA, was used during this experiment. The Mastersizer 3000 utilizes the laser diffraction technique to measure particle sizes of ground material. It measures the angular variation in intensity of light scattered as a laser beam passes through a dispersed particulate sample. Larger particles scatter light intensely at small angles relative to the laser beam whereas smaller particles scatter light weakly at large angles. This angular scattering intensity data can then be transformed into particle size distribution result for the ground material. Mie theory of light scattering is used to calculate the particle size distribution and assumes the volume equivalent sphere model. The Mie theory makes certain assumptions that the particle is spherical, ensemble is homogeneous, and the refractive index of particle and surrounding medium is known.

Traditionally, particle size distribution of coffee has been measured using sieve based methods. But these methods are labor intensive and accuracy of the particle size distribution results for milled product very questionable. Recent advancement in laser diffraction technology has led to development of high intensity, reasonably priced bench size instruments that have been widely accepted for characterization of time sensitive products like coffee. Particle size distribution measurement of samples of ground coffee is commonly used to ensure consistency during grinding operations.

Laser diffraction systems are the most popular particle size technique for reasons including ease of set up, rapid measurements (size distributions in seconds), flexibility, and provide robust results not requiring user intervention [13,18]. Laser diffraction instruments can measure solid particles in suspensions and emulsions. This technique enables rapid assessment of milling progress of coffee before it oxidizes, thereby preserving its flavor.

2.3 Color Measurements

Color measurements of all coffee samples were made using a portable CR-400 tristimulus colorimeter (Minolta Chroma Meter CR 400, Osaka, Japan) and Spectra-Match software, set to L^*, a^*, b^* mode. Colorimeter measures color and surface darkness/lightness to a precise degree by illuminating the sample with a pulse of light of defined color or brightness from xenon arc lamp. Color measurements were recorded for two replicates of each sample. L^* values correspond to levels of darkness/lightness between black ($L^* = 0$) and white ($L^* = 100$), a^* values signify the balance between red ($a^* = +100$) and green ($a^* = -100$), and b^* between yellowness ($b^* = +100$) and blue ($b^* = -100$).

2.4 Statistical Analysis

All data were analyzed using SAS, Software Release 9.1.3. The data were statistically analyzed using two-way ANOVA ($P \leq 0.05$) applied to the studied coffee samples for both particle size analysis and color measurements. Based on the ANOVA results, the Tukey's test was performed for mean comparison at 95% confidence level.

3. RESULTS AND DISCUSSION

3.1 Particle Size Distribution of Roasted Coffee Ground at Different Grinding Times

The particle size distribution of the roasted ground coffee samples that underwent grinding at different time periods was based on volume distribution as shown in Fig. 1. Samples with coarser particles had distributions skewed to the right hand side where as finer samples had distributions skewed to the left hand side.

Coffee samples ground for short times i.e. 30s, 20s and 10s, were observed to have coarser particles when compared to the coffee samples that underwent longer grinding times. This shows that the longer the grinding time, the finer or more uniform the particles obtained.

Table 1 below shows the least squares means comparison for the D value measurements for the coffee samples ground at different time intervals. It was observed that the longer the roasted samples are ground, the finer the particles obtained. At 10 seconds (10s) grinding time, it is shown that over 90% of the particles are smaller than 2480 µm which is much higher than 1105.0 µm particle size (D90) when grinding lasts for 60 seconds.

The D10 mean values range from 645.5 to 61.45 µm; D50 mean values ranged from 1385.0 to 613.0 µm; whereas, the D90 mean values ranged from 2480.0 to 1105.0 µm. The multiple comparison of the least squares means showed few significant differences for the D10, D50 and D90 for the 20s, 30s and 40s samples. The coffee samples ground for 10s, showed significant differences (at P = 0.05) in the volume particle size distribution for all the D values when compared to all the other grinding times. The 20s and 30s grinding times did not exhibit any significant differences for the D50 and D90 particle size distributions. Generally, the 60s grinding time for the coffee samples exhibited a much finer sample when compared to all the other grinding times although for all the D values it shows no significant difference from the 50s at P = 0.05. Highly significant differences (at P = 0.05) were observed for all the different coffee samples at the different D values with p-values < 0.0001.

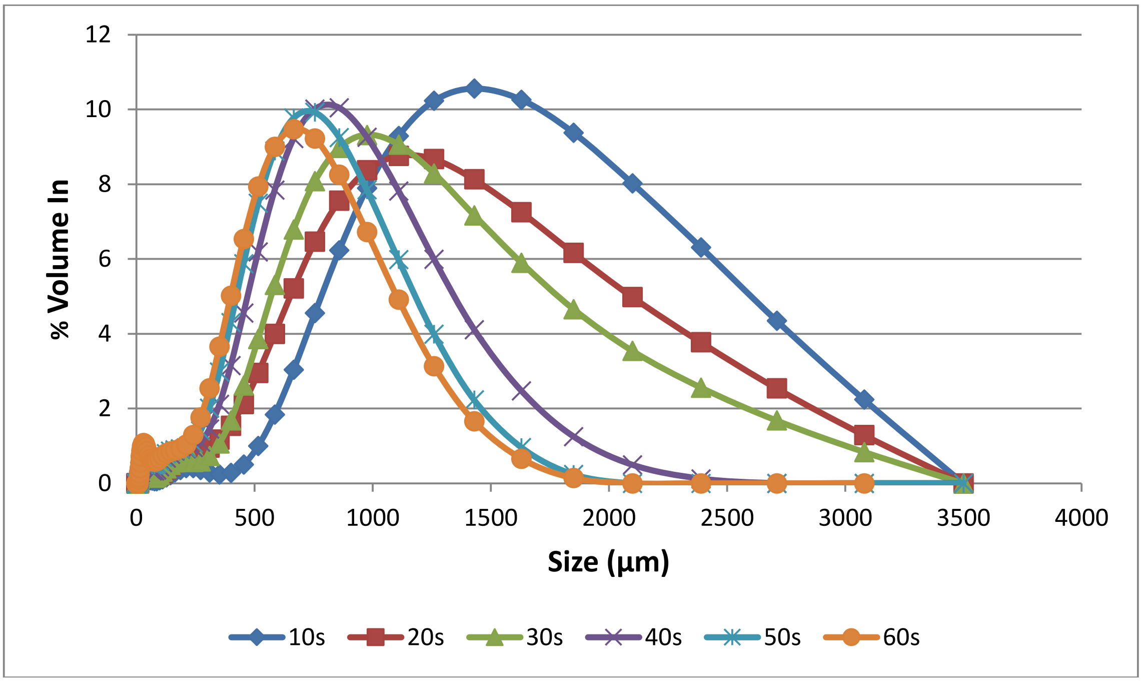

Fig. 1. Particle size distribution of roasted coffee ground at different time periods in seconds

Table 1. D values for roasted coffee samples ground for different time periods

Coffee samples	D10 (µm)	D50 (µm)	D90 (µm)
10s	645.5[a]	1385.0[a]	2480.0[a]
20s	420.5[b]	1145.0[b]	2260.0[b]
30s	398.5[b,c]	1040.0[b]	2060.0[b]
40s	192[c,d]	781.5[c]	1440.0[c]
50s	140.5[d]	710.5[c,d]	1270.0[c,d]
60s	61.45[d]	613.0[d]	1105.0[d]

**within columns, means followed by the same letter are not significantly different at P = 0.05 probability level. The letters correspond to the coffee samples ground for different time frames in first column. Multiple comparison was adjusted for the p-value using the Tukey-Kramer method*

3.2 Particle Size Distribution of Different Coffee Brands

From Fig. 2, it was observed that Antiqua brand has the most extreme right hand side skew of the particle size distribution when compared to all the other coffee brand samples. Najjar brand was the finest, followed by 1820b then 1820a and Sanchez classic. Leyenda and Tarrazu did not exhibit any significant differences in the shape of their particle size distribution. Najjar brand particle size distribution was skewed to the far left side with largest particle size ~500 µm.

From Table 2 above, there was no significant difference in D50 and D90 values for Colombian 1.3, Leyenda and Tarrazu brands. But these brands showed significant differences within the D10 values (*P* = 0.05). There was high significant differences between the different brands when compared at the smallest particle size distribution values but with Leyenda, Tarrazu and Sanchez Classic exhibiting no significant differences at *P* = 0.05. Najjar brand had the smallest particle size distribution hence the finest and significantly different from all the other coffee brands at *P* = 0.05.

3.3 Particle Size Distribution Comparison of All Coffee Samples

Table 3 below shows the least squares means differences of all coffee samples D values particle size distributions. A statistically significant difference between the D10, D50 and D90 values for between all the coffee samples at *P* = 0.05 with P-values of <0.0001.

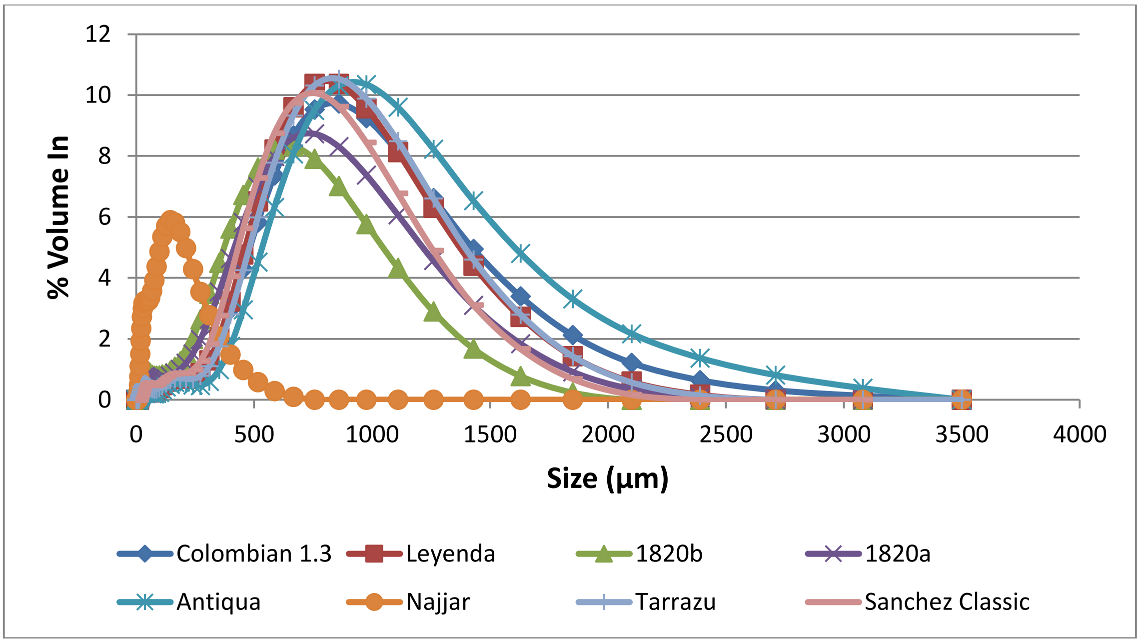

Fig. 2. Volume based Particle size distribution of different coffee brands

Table 2. Particle size distribution (D values) for different coffee brand samples

Coffee Brand	D10 (µm)	D50 (µm)	D90 (µm)
Antiqua	405.5^{a}	946.0^{a}	1775.0^{a}
Colombian 1.3	301.5^{b}	803.0^{b}	1430.0^{b}
Leyenda	235.0^{c}	800.5^{b}	1425.0^{b}
Tarrazu	$226.5^{c,d}$	794.0^{b}	1420.0^{b}
Sanchez Classic	176.0^{d}	728.0^{c}	1335.0^{c}
1820a	118.0^{e}	667.0^{d}	1295.0^{c}
1820b	63.95^{f}	573.0^{e}	1125.0^{d}
Najjar	25.25^{f}	109.0^{f}	278.5^{e}

**within columns, means followed by the same letter are not significantly different at P = 0.05 probability level. The letters correspond to the coffee samples ground for different time frames in first column. Multiple comparison was adjusted for the P-value using the Tukey-Kramer method*

Table 3. Means of coffee samples particle size distribution values (D values)

Coffee samples	D10 (μm)	D50 (μm)	D90 (μm)
10s	645.50^{a}	1385.00^{a}	2480.00^{a}
20s	398.50^{b}	1145.00^{b}	2260.00^{b}
30s	420.50^{b}	1040.00^{b}	2060.00^{c}
40s	192.00^{c,d,e}	781.50^{d}	1440.00^{e}
50s	140.50^{f,d,e}	710.50^{e,d}	1270.00^{g}
60s	61.45^{f,e}	613.00^{g,f}	1105.00^{h}
Antiqua	405.50^{b}	946.00^{c}	1775.00^{d}
Colombian 1.3	235.00^{c,d}	794.00^{d}	1430.00^{f,e}
Leyenda	301.50^{c,b}	800.50^{d}	1420.00^{f,e}
Tarrazu	226.50^{c,d}	803.00^{d}	1425.00^{f,e}
Sanchez Classic	176.00^{c,d,e}	728.00^{e,d}	1335.00^{f,e,g}
1820a	118.00^{f,d,e}	667.00^{e,g,f}	1295.00^{f,g}
1820b	63.95^{f,e}	573.00^{g}	1125.00^{h}
Najjar	25.25^{f}	109.00^{h}	278.50^{i}

*****within columns, means followed by the same letter are not significantly different at P = 0.05 probability level. The letters correspond to the coffee samples ground for different time frames in first column. Multiple comparison was adjusted for the P-value using the Tukey-Kramer method*

It was also observed that Najjar brand had the smallest particle sizes (finest coffee sample) when and was highly significantly different from all the rest (P = 0.05). The ground roasted coffee sample that was ground for 10s was significantly different from all the rest (at P = 0.05) exhibiting coarse particles.

3.4 Color Measurements for the Coffee Samples

Table 4 below shows the least squares means comparison for the color measurements for the coffee samples ground at different time intervals.

The analysis of the chromatic parameters, showed that lightness (L^*) as well as parameters a^* and b^* were highly significantly different between the different coffee samples (at P = 0.05) with P-value of <0.0001. It was observed that the coffee samples that underwent grinding for 60s had the highest L^*, a^* and b^* values of 30.72, +1.31 and +1.39 respectively. Colombian 1.3 coffee brand had the lowest L* and a* values of 29.8 and +0.67 respectively, with brand 1820a having the lowest b* value of +0.39. It was also observed that these two brands Colombian 1.3 and 1820a had no significant differences for all the L^*, a^* and b^* values at P = 0.05. This showed that Colombian 1.3 as well as 1820a brands exhibited darker color (medium brown), with more towards greenish color for a^* and least yellow for b^*. Brown-black color of coffee particles occurs during roasting, this is described by a decrease of L^* as well as of a^* and b^* values. The coffee ground for 60s had the highest luminosity, towards reddish and yellowish color combination hence towards light brown. Classification of differently roasted coffee samples on the basis of L^* color values as light, medium, or dark roasted with L^* values of 31.2, 26.0, and 24.3 respectively [19].

Color is one of the important variables used to predict the degree of coffee roasting hence controlling the consistency and quality of roasted coffee products in the coffee industry [20]. Color change during roasting is mainly due to non-enzymatic browning reactions such as Maillard reaction and caramelization [11]. When color for the various samples were compared with their particle sizes, the coffee brands, Antiqua which had the largest particle size distribution and Najjar which had the smallest particle size distribution did not exhibit any significant differences for L^*, a^* and b^* values at P = 0.05. This result implied that particle size difference did not affect or influence the color of the ground coffee brands.

As a result, the degree of coffee roasting at which these coffee brands were obtained is comparable. The second family of roasted ground coffee had greater a^* and b^* values than the first family of the various coffee brands, it was also discovered. As a result, the coffee brands in the first family of samples are much lighter (less browning) and more yellow. There was also no significant difference between the 10s, 20s, 30s, 40s, 50s, and 60s coffee samples at P = 0.05, indicating that size reduction time has no effect on the color of the ground coffee.

Table 4. Means of coffee samples color measurements

Coffee samples	L*	a*	b*
10s	$30.12^{e,d,f}$	$+1.03^{g,e,f,d}$	$+0.78^{f,d,e}$
20s	$30.19^{c,d,e}$	$+1.09^{c,e,b,d}$	$+0.99^{b,d,e,c}$
30s	$30.29^{c,d}$	$+1.33^{b}$	$+1.16^{b,a,c}$
40s	$30.37^{c,b}$	$+1.28^{c,b,d}$	$+1.30^{b,a}$
50s	$30.22^{c,d,e}$	$+1.31^{c,b}$	$+1.11^{b,d,a,c}$
60s	30.72^{a}	$+1.63^{a}$	$+1.39^{a}$
Antiqua	$30.17^{c,d,e}$	$+1.02^{g,e,f,d}$	$+0.68^{f,e,g}$
Colombian 1.3	29.80^{g}	$+0.67^{h}$	$+0.48^{f,g}$
Leyenda	$30.05^{f,e}$	$+0.81^{g,f,h}$	$+0.59^{f,g}$
Tarrazu	$30.09^{f,d,e}$	$+0.95^{g,e,f}$	$+0.40^{g}$
Sanchez Classic	30.51^{b}	$+1.23^{c,b,d}$	$+0.80^{f,d,e,c}$
1820a	$29.93^{f,g}$	$+0.78^{g,h}$	$+0.39^{g}$
1820b	$30.18^{c,d,e}$	$+1.05^{c,e,f,d}$	$+0.62^{f,e,g}$
Najjar	$30.28^{c,d}$	$+1.25^{c,b,d}$	$+0.67^{f,e,g}$

****within columns, means followed by the same letter are not significantly different at P = 0.05 probability level. The letters correspond to the coffee samples ground for different time frames in first column. Multiple comparison was adjusted for the p-value using the Tukey-Kramer method*

4. CONCLUSION

In conclusion, the particle size distribution of coffee samples had no effect on the color of ground coffee particles. Due to the darkening of the beans caused by sugar caramelization and Maillard reactions, the *L**, *a**, and *b** values drop during roasting. There was no significant difference between the 10s, 20s, 30s, 40s, 50s, and 60s coffee samples at P = 0.05, indicating that size reduction time has no effect on the color of the coffee particles.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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