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Colorimetric patterns of wood pellets and their relations with quality and energy parameters

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HIGHLIGHTS

- This study aims to verify the correlation between color and quality parameters of wood pellets.
- Result proved that color differences are perceptible by human eye.
- It is possible to observe good correlations between ash and CIE $L^*a^*b^*$ (pellet and GAS), RGB and HSV values.
- Sample lighter in color mainly clustered in the space where HHV, DU and densities have higher scores.
- Darker samples were dispersing in the opposite space dominated by higher ash and moisture contents.

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ABSTRACT

Color of wood pellets is mainly affected by the feedstock material used for their production and which composition and characteristic affect the final product quality. Pellets made from pure wood are light in color and have low ash content, while pellets made from different mixtures of wood and bark or foliage are generally darker and richer in minerals. This study aims to verify the correlation between color and quality parameters of wood pellets available on the Italian market. All the samples were analyzed following the procedures laid down by the European Norms (EN) on solid biofuels for moisture, ash, calorific value, durability, bulk and solid density. The acquisition of the images was done with two techniques: the CIE $L^*a^*b^*$ color space and RGB-HSV color spaces. Canonical correlation analysis (CCA) was performed with CIE-L^*a^*b, RGB and HSV separately showing for all the color components good degree of correlation with ash content of pellets. The PCA analysis on two principal components (total explained variance: 64.2%) showed a clear color gradient moving form good to medium or low quality parameters. This pattern is confirmed by the clustering of certified pellets in the region of lightest samples. The calculation of ΔE and ΔRGB showed a good discrimination level between whole pellets samples and their sawdust, and between ones with high and low ash content. The visual predictability of pellets quality on the basis of their color is however not so sharp when considering samples with similar colors. The industrial applicability of such methods for the evaluation of pellets quality is desirable for RGB methodologies that are less expensive and more reliable in working condition, given that specific color calibration is performed.

1. Introduction

Wood pellets are one of the wider internationally spread biofuel commodities for energy production and their market is booming in Europe [1] mainly driven by the fairly low cost per energy unit and the European and National subsidy systems to achieve the 2020 targets. Nowadays the continuous increasing demand in wood pellets seems not to be totally met by the domestic production, not for technology limitation, but for shortage in primary resources and due to the competition with large power plants [2] and wood industry. Even if specific and accurate statistics for pellets sector are missing, the European market is dependent on importation [3] and the ENplus annual report underlines that the Italian import

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Abbreviations

A	ash content	GAS	General Analysis Sample
a^*	color coordinate along the *X* axis red (+) to green (−)	HHV_{ar}	high heating value as received
AbDe	Norway spruce debarked stem	HHV_{daf}	high heating value on dry basis and ash free
AbSt	Norway spruce whole stem	HSV	hue, saturation, lightness (color space)
AbTr	Norway spruce whole tree	HV	heating value
b^*	color coordinate along the *Y* axis yellow (+) to blue (−)	ISO	International Organization for Standardization
BD	bulk density	*L*	length
CCA	canonical correlation analysis	L^*	lightness (color coordinate)
CCD	charge-coupled device	*M*	moisture content
CIE	Commission Internationale de l'Eclairage	m_b^{-3}	bulk cubic meter
CMOS	complementary metal-oxide-semiconductor	NIR	near-infrared
D	particle density	PCA	Principal Component Analysis
d.p.i	dots per inch	RGB	Red, Green, Blue (color space)
DU	mechanical durability	ROI	region of interest
EN	European Norm	sRGB	standard Red, Green, Blue (color space)
F	fines content	TPS	Thin Plate Spline
FaBr	beech branches	$\%_{ar}$	percentage as received
FaSt	beech whole stem	Ø	diameter

of wood pellets from abroad (within EU-27, Canada, United States, South America and New Zealand) is actually filling the gap between the domestic production and consumption[4].

Compared with other biofuels, pellets have higher energy density, lower transportation and storage costs [5,6] and their regular shape allows the automation of feeding procedure in burning appliances [7]. These are some of the reasons why wood pellets have a wide diffusion on the biofuels market. Wood pellets final quality is affected by a series of different parameters, both deriving from intrinsic feedstock characteristics, and treatment or production conditions.

Raw materials properties affect pellets quality as soon as their constituents are found nearly unchanged in the final product. Tree species and wood provenance has been found to influence the pelletizing process [8], and the final pellet quality [9,10], especially if related with the sawdust particle size distribution and its content in fatty acids [11,12]. The total amount of ash in the biofuel is also related with tree species introduced in the blend of feedstock as different woods are characterized by different amount of unburnt residues [13].

The color of pellets made from pure wood sawdust, processing residues or debarked stems and shavings have generally lighter colors. The absence of bark results in lower ash contents compared with wood [14,15] but, on the other hand, in low mechanical properties, especially durability [16], that detects the proneness of pellet to disintegrate when exposed to mechanical stresses. This can results in higher fine particles content that affects pellets quality during transportation, storing, stove feeding and final burning [14]. Pellets produced from whole stems, including bark or mineral contaminants, are instead darker in color and usually their ash content is higher [17], lowering the content of energetic matter in the biofuel and the quality of the combustion behavior, to the point that pure bark pellets can be burnt only in large heating plants [14].

Storage conditions of raw material, that can modify the chemical constitution of wood, influence the mechanical compaction behavior of the sawdust. In particular the natural seasoning and low temperature drying results in more durable pellets compared with ones made from artificially and fast dried at high temperatures [14]. The exposure of raw material to high temperatures during drying changes both its chemical properties and external appearance affecting also the resulting pellet color [18,19]. Heat exposure, in fact, modifies the wood structure and color in dependence of temperature and presence or absence of oxygen [20].

The moisture in the feedstock as bound water plays a key role in the formation of interparticles linkages. Moister feedstock results in weaker pellets, to the point that sawdust is no longer able to remain compacted after exiting the die channel. On the other hand, the moisture content, acting as lubricant, can affect positively the resulting pelletizing pressure and temperature [21], again influencing the final color result [17]. The optimal ranges for water content values are found to be 8–13% [9,14].

This variability in pellets quality parameters has stimulated many countries to develop specific standards and regulations in the attempt to set some baselines for production, storage and distribution of wood pellets [7]. The national standardization process has resulted, by the end of 2012, to the publication of some harmonized EN (European Norms) regulating pellets quality parameters and classes.

The experience developed in the study of the wood pellet sector for residential heating has shown that a strong emphasis is put on the color of pellets due to the fact that the market is very reactive to this parameter, and this is verified considering that dark color pellets have a lower commercial value than light wood pellets [17] (the so called "white pellets"), especially for residential applications. In fact consumers tend to associate the darker color with the contamination of raw materials with impurities such as bark, which high ash content is reflected in the final pellet quality.

Even if color is not a parameter for grading pellets quality as defined by the European and International Norms (EN–ISO), the market trend and the consumer choice are strongly affected by this parameter that is the only one directly verifiable at first sight [22,23]. On the other side, this consideration is not supported by scientific studies and a lack of knowledge regarding color and quality applied to pellet properties is registered. Very little literature is available (mainly on change in color of feedstock that underwent thermal drying) and no clear relationships among pellet characteristics and its color have been proved.

Each color depends on the type of emission source that irradiates an object, as well as on the physical properties of the object itself (which reflects the radiation consequently detected by the sensor), and finally on the in-between medium (e.g., air or water) [24]. Generally, the color spaces applied for product classification are the standard RGB (sRGB; red, green, blue) and CIE $L^*a^*b^*$. sRGB