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Research Paper

Class-based physical properties of air-classified sunflower seeds and kernels

Simon Munder, Dimitrios Argyropoulos, Joachim Müller*

University of Hohenheim, Institute of Agricultural Engineering, Tropics and Subtropics Group, Garbenstraße 9, 70599 Stuttgart, Germany

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High oleic sunflower seeds, with higher oil content and greater oleic acid content than other sunflower seeds, are gaining in economic importance. However, there are still major gaps in knowledge concerning their post-harvest handling. This study was carried out, to establish a simply implemented method of classifying the seeds via air-separation, which allows rapid and precise assignment of high oleic sunflower seeds into different quality classes. Physical properties were evaluated and compared to earlier studies. A low hull to kernel ratio of 0.26 ± 0.04 was found, with seed masses ranging from 0.024 to 0.108 g. A high positive correlation between seed mass and kernel mass ($r = 0.993$) was observed but negligible correlations between seed length, width, thickness and mass were found. Seed mass analysis from the air-separation classes indicated highly precise (F_1 score $= 0.966$) allocation into mass based classes, with below 5% false positives. Thus, a significant difference between hull to kernel ratio, bulk density, porosity, sphericity, the angle of repose, and rupture force in vertical and transversal orientation was found for the different classes. Rupture force in the horizontal orientation, true density and static friction did not reveal any class differences. Threshold values for air velocity where therefore established for air-separation that can classify seeds of different qualities and optimise postharvest seed handling operations.

1. Introduction

Sunflower is a major oil crop and source of vegetable oils (de Figueiredo, Baümler, Riccobene, & Nolasco, 2011; Gupta & Das, 1997; Mirzabe, Khazaei, & Chegini, 2012). Sunflower cultivated for oil extraction can be classified into three main groups, based on the fatty acid profiles: (i) traditional with 14–39% oleic acid, (ii) medium-oleic with 42–72% oleic acid and high-oleic with 75–91% oleic acid (Zheljazkov et al., 2010). High oleic genotypes carry the Pervenets mutation, which raises the oleic acid content to above 75% (Lacombe, Kaan, Griveau, & Bervillé, 2004). These genotypes also maintain a high oleic acid level when grown at lower temperatures (Ferfuia, Turi, & Vannozzi, 2015; Garcés, García, & Mancha, 1989). Due to the low content of poly-unsaturated fatty acids, the high oxidative stability and the high heat stability, high oleic acid sunflower oil is especially suitable for nutritional purposes, such as deep frying applications, and also as raw material for the oleo-chemical industry and the

* *Corresponding author*. Fax: +49 711 459 23298.
E-mail address: info440e@uni-hohenheim.de (S. Munder).
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Nomenclature

mm	millimetre
m	metre
km	kilometre
mg	milligram
g	gram
kg	kilogram
RH	relative humidity, %
L	length of seed, mm
l	length of kernel, mm
W	width of seed, mm
w	width of kernel, mm
T	thickness of seed, mm
t	thickness of kernel, mm
D_e	equivalent diameter, mm
Ψ	sphericity
V	volume, mm^3
m_a	air mass flow, kg s^{-1}
V_a	terminal velocity, m s^{-1}
V_t	terminal velocity required to fluidise 50% of sample mass, m s^{-1}
β_1, β_2, dV	experimentally determined coefficients of the Boltzmann equation
DIN	German Industrial Standard
Pa	Pascal
C_d	discharge coefficient
ε	expansibility factor
A_O	open area of orifice place
ρ_A	density of air, kg m^{-3}
A_T	cross sectional area of conveyor tube, m^2
ρ_t	true density, kg m^{-3}
M_s	mass of seeds, kg m^{-3}
ρ_T	density of toluene, kg m^{-3}
M_T	mass of toluene displace by seeds, kg
V_V	volume of bulk density measurement vessel, m^3
ρ_b	bulk density, kg m^{-3}
ϕ	porosity
ϕ_{calc}	calculated porosity
P	pressure, Pa
N	Newton
kN	kiloNewton
F_R	rupture force, N
min	minute
μ_s	coefficient of static friction
$\vec{F}_S$	force required to slide an idling object, N
$\vec{F}_N$	normal force, N
$\vec{F}_{GH}$	downhill force, N
$\vec{F}_{GN}$	force of static friction, N
$\vec{F}_G$	gravitational force, N
ω	angular velocity, s^{-1}
$\theta_{dynamic}$	dynamic angle of repose
θ_{static}	static angle of repose
r	Pearson's product moment correlation coefficient
R^2	coefficient of determination
RMSE	root mean squared error
F_1 score	score for goodness of classification
P	precision
R	recall
tp	true positives
fp	false positives
fn	false negatives
ANOVA	analysis of variance
Tukey's HSD	Tukey's honest significant difference test
p	probability level at which significance is assumed
H_s	hull to seed ratio
H_K	hull to kernel ratio

production of lubricants, hydraulic-oils and other oils used for technical applications (de Figueiredo et al., 2011; Santalla & Mascheroni, 2003b; Weimar, Anderl, & Goetz, 2006). To date, traditional sunflower varieties are the main varieties that are commercially grown, but high oleic sunflower varieties are gaining economic importance (Santalla & Mascheroni, 2003b; Weimar et al., 2006).

Progress in breeding has produced modifications in the physical properties of both, seeds and kernels. Up-to-date knowledge of these properties, is crucial for the proper design and operation of agricultural machinery and equipment for drying, hulling, storage, and oil extraction (Gupta & Das, 1997; Santalla & Mascheroni, 2003b). Knowledge of the morphology and the distribution of morphological characteristics is the basis of post-harvest processes, such as drying, hulling, transportation or mechanical oil extraction (Gupta & Das, 1997; Santalla & Mascheroni, 2003a). Aerodynamic properties and seed size are crucial properties in design and adjustment of combine harvesters, where usually a winnowing system is the first cleaning operation, followed by several sifting steps (Kutzbach, 2001). Seed size, density and shape directly influence aerodynamic properties (Albar, 2000). Size, density, and hull structure do also affect hulling efficiency (de Figueiredo et al., 2011). Knowledge of sphericity, static friction, and the angle of repose is valuable in the design of conveyors and storage facilities. Porosity plays a major role in design of solvent based extraction methods (de Figueiredo et al., 2011). Fracture characteristics such as rupture force are dependent on most of the above named properties and are crucial for the design of hulling and oil extraction equipment (Selvam, Manikantan, Chand, Sharma, & Seerangurayar, 2014). There are only few studies, reporting on the physical properties of sunflower seeds or classification options to increase homogeneity. Gupta and Das (1997) tested the correlation of seed and kernel dimensions of a traditional variety mainly grown in India (Morden) and they established three size categories (small, medium, large) and provided the ranges of seed and kernel dimensions and masses. The effect of moisture content on physical properties such as density, terminal velocity and static friction was also investigated, but this was not related to the size categories. Santalla and Mascheroni (2003a, 2003b) focused on the description of the physical properties of an Argentinian high oleic variety (Trisum 568) and followed a methodology very similar to that of Gupta and Das (1997), but they also did not refer to size categories in the description of physical properties, even though, they explicitly stated, that