Physicochemical and Functional Properties of Fiber-rich Hulls from Different Pulses: A Comparative Study

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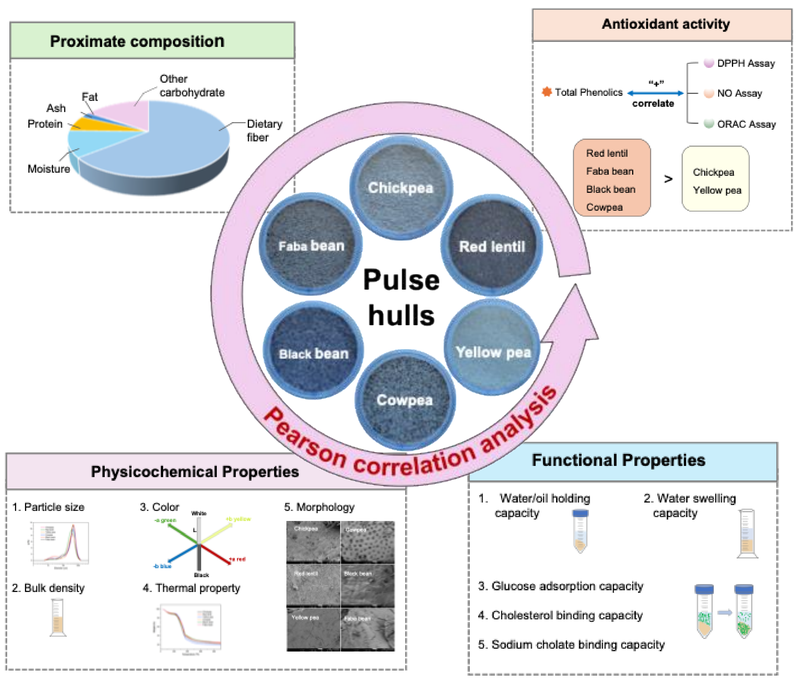
INTRODUCTION

- Pulses, the dry edible seeds of legumes, are increasingly recognized as one of the most important food sources to address the increasing concerns over food insecurity and malnutrition, due to their nutritional, environmental, and health benefits.
- Pulses generally undergo a series of post-harvest processing steps such as dehulling, leaving a significant amount of hulls, which is an important source of dietary fiber while they have been traditionally used as low-value animal feed.
- Upcycling pulse hulls for high-value applications is essential to improve the economic and sustainability of the pulse industry.

OBJECTIVES

- Comprehensively analyze the chemical compositions, physicochemical attributes, and functional properties of the hulls derived from the six most prominent pulses (i.e., chickpea, red lentil, yellow pea, cowpea, black bean, and faba bean).
- Correlation analysis of pulse hull properties.

MATERIALS AND METHODS



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RESULTS

➢ Pulse hull properties

Table 1. Proximate composition of different pulse hulls (as-is basis)

	Crude protein (%)	Crude fat (%)	Ash (%)	Moisture (%)	Total carbohydrate (%)	Total dietary fiber (%)
Chickpea	8.52 ± 0.13 ^{d}	0.71 ± 0.06 ^{a}	5.03 ± 0.21 ^{a}	12.27 ± 0.08 ^{a}	73.48 ± 0.36 ^{d}	49.11 ± 1.70 ^{b}
Red lentil	12.08 ± 0.23 ^{b}	0.07 ± 0.03 ^{d}	2.58 ± 0.05 ^{c}	10.38 ± 0.01 ^{d}	74.90 ± 0.24 c	50.66 ± 0.08 ^{b}
Yellow pea	6.60 ± 0.31 ^{e}	0.01 ± 0.01 ^{d}	2.23 ± 0.08 ^{c}	11.20 ± 0.04 ^{c}	79.97 ± 0.18 ^{b}	64.70 ± 0.54 ^{a}
Cowpea	13.91 ± 0.28 ^{a}	0.35 ± 0.02 ^{b}	4.12 ± 0.62 ^{b}	12.26 ± 0.01 ^{a}	69.37 ± 0.86 ^{e}	50.10 ± 1.39 ^{b}
Black bean	10.08 ± 0.09 ^{c}	0.19 ± 0.04 ^{c}	3.73 ± 0.03 ^{b}	11.85 ± 0.02 ^{b}	74.17 ± 0.05 ^{cd}	50.11 ± 1.09 ^{b}
Faba bean	3.94 ± 0.13 ^{f}	0.00 ± 0.00 ^{d}	2.65 ± 0.09 ^{c}	11.77 ± 0.18 ^{b}	81.65 ± 0.22 ^{a}	65.43 ± 0.40 ^{a}

Table 2. Particle size distribution of different pulse hulls

	$D_{4,3}$ (μm)	D_{10} (μm)	D_{50} (μm)	D_{90} (μm)
Chickpea	395.61 ± 5.43 ^{a}	67.65 ± 0.47 ^{b}	392.55 ± 5.13 ^{a}	680.17 ± 12.15 ^{a}
Red lentil	315.14 ± 3.77 ^{c}	91.87 ± 10.82 ^{a}	291.57 ± 4.63 ^{c}	558.69 ± 1.06 ^{c}
Yellow pea	373.84 ± 0.27 ^{ab}	80.56 ± 2.14 ^{ab}	366.92 ± 0.88 ^{ab}	639.34 ± 0.33 ^{b}
Cowpea	356.28 ± 3.68 ^{b}	49.23 ± 3.25 ^{c}	344.79 ± 3.80 ^{b}	651.00 ± 3.97 ^{ab}
Black bean	302.79 ± 26.53 ^{c}	30.17 ± 7.63 ^{d}	284.95 ± 28.96 ^{c}	579.65 ± 25.35 ^{c}
Faba bean	364.31 ± 4.31 ^{ab}	75.66 ± 3.68 ^{b}	361.49 ± 0.32 ^{ab}	634.65 ± 9.27 ^{b}

Table 3. Physicochemical properties of different pulse hulls

	Bulk density (g/L)	Color		
		L*	a*	b*
Chickpea	504.88 ± 9.02 ^{d}	71.12 ± 2.01 ^{b}	4.85 ± 0.17 ^{c}	19.57 ± 0.71 ^{a}
Red lentil	621.62 ± 3.82 ^{b}	46.34 ± 1.37 ^{f}	7.94 ± 0.19 ^{a}	15.24 ± 0.28 ^{d}
Yellow pea	672.51 ± 20.22 ^{a}	79.04 ± 0.88 ^{a}	1.67 ± 0.08 ^{f}	18.55 ± 0.57 ^{b}
Cowpea	595.80 ± 18.49 ^{bc}	62.07 ± 1.36 ^{c}	3.48 ± 0.17 ^{e}	14.87 ± 0.28 ^{d}
Black bean	648.47 ± 8.06 ^{a}	52.03 ± 1.83 ^{e}	4.02 ± 0.17 ^{d}	6.92 ± 0.46 ^{e}
Faba bean	587.75 ± 6.67 ^{c}	60.29 ± 0.86 d	7.74 ± 0.17 ^{b}	17.94 ± 0.55 ^{c}

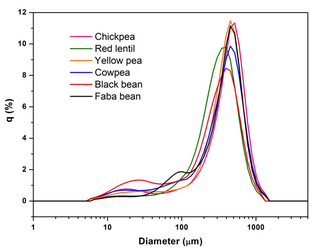

Figure 1. Particle size distribution of different pulse hulls.

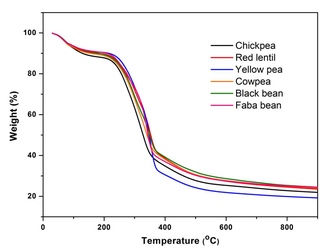

Figure 2. TGA profiles of different pulse hulls.

Table 4. Functional properties of different pulse hulls

	WHC (g/g)	WSC (mL/g)	OHC (g/g)	GAC (mg/g)	CBC (mg/g)	SCBC (mg/g)
Chickpea	5.91 ± 0.09 ^{a}	4.17 ± 0.17 ^{a}	1.48 ± 0.01 ^{a}	230.27 ± 13.54 ^{d}	19.09 ± 1.38 ^{cd}	22.38 ± 0.81 ^{b}
Red lentil	3.14 ± 0.05 ^{d}	1.69 ± 0.05 ^{c}	1.24 ± 0.01 ^{c}	308.01 ± 7.61 ^{a}	135.19 ± 6.47 ^{a}	16.61 ± 0.57 ^{c}
Yellow pea	3.40 ± 0.05 ^{c}	2.19 ± 0.05 ^{b}	1.15 ± 0.01 ^{d}	268.97 ± 9.65 ^{b}	13.83 ± 0.33 ^{d}	21.51 ± 0.95 ^{b}
Cowpea	3.15 ± 0.11 ^{d}	1.58 ± 0.08 ^{c}	1.44 ± 0.01 ^{b}	234.77 ± 12.86 ^{cd}	17.78 ± 1.96 ^{cd}	29.89 ± 1.40 ^{a}
Black bean	3.19 ± 0.03 ^{d}	1.33 ± 0.00 ^{d}	1.15 ± 0.02 ^{d}	258.33 ± 5.33 ^{bc}	22.82 ± 1.52 ^{c}	22.52 ± 1.07 ^{b}
Faba bean	4.33 ± 0.09 ^{b}	2.05 ± 0.10 ^{b}	1.43 ± 0.02 ^{b}	294.86 ± 14.05 ^{a}	51.51 ± 4.76 ^{b}	21.53 ± 1.00 ^{b}

Table 5. Antioxidant activity of different pulse hulls

	TPC (mg GAE/g)	DPPH• (mg TE/g)	NO• (mg TE/g)	ORAC (μmol TE/g)
Chickpea	0.75 ± 0.01 ^{e}	0.24 ± 0.01 ^{e}	4.73 ± 0.19 ^{c}	19.22 ± 0.20 ^{e}
Red lentil	35.70 ± 0.55 ^{a}	86.21 ± 4.21 ^{a}	11.09 ± 0.13 ^{a}	793.37 ± 5.49 ^{a}
Yellow pea	0.68 ± 0.01 ^{e}	0.20 ± 0.00 ^{e}	4.13 ± 0.07 ^{c}	15.41 ± 0.59 ^{e}
Cowpea	8.54 ± 0.08 ^{d}	15.30 ± 0.11 ^{d}	4.46 ± 0.28 ^{c}	207.58 ± 3.62 ^{d}
Black bean	18.07 ± 0.20 ^{c}	38.05 ± 0.82 ^{c}	10.60 ± 0.53 ^{a}	287.21 ± 16.47 ^{c}
Faba bean	27.24 ± 0.73 ^{b}	53.49 ± 0.46 ^{b}	9.56 ± 0.81 ^{b}	334.47 ± 0.09 ^{b}

RESULTS

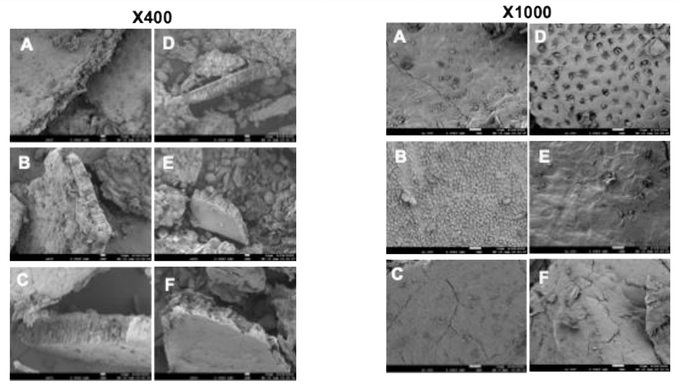

Figure 3. SEM micrographs of chickpea (A), red lentil (B), yellow pea (C), cowpea (D), black bean (E), and faba bean (F) hulls. Images were obtained at magnifications of ×400, and ×1000. White scale bars represent 10 μm.

➢ Correlation analysis

Table 6. Pearson correlation coefficients ® for the relationships between chemical compositions, physicochemical attributes, functional properties, and antioxidant activities of pulse hull samples

	PC	FC	AC	MC	TC	TDF	L*	a*	b*	BD	D4,3	WHC	OHC	WSC	GAC	SCBC	CBC	TPC	DPPH	NO	ORAC
PC	1	0.307	0.365	-0.037	-0.907*	-0.817*	-0.435	-0.116	-0.416	0.025	-0.434	-0.432	-0.022	-0.303	-0.295	0.33	0.206	0.055	0.12	-0.024	0.331
FC		1	0.956**	0.643	-0.642	-0.662	0.239	-0.174	0.164	-0.806	0.446	0.685	0.589	0.728	-0.808	0.378	-0.374	-0.544	-0.521	-0.47	-0.437
AC			1	0.762	-0.715	-0.717	0.089	-0.167	-0.074	-0.74	0.276	0.565	0.572	0.54	-0.839*	0.511	-0.438	-0.464	-0.463	-0.346	-0.404
MC				1	-0.353	-0.185	0.361	-0.35	-0.019	-0.531	0.452	0.47	0.596	0.348	-0.828*	0.791	-0.806	-0.585	-0.657	-0.48	-0.706
TC					1	0.902*	0.257	0.2	0.346	0.293	0.183	0.095	-0.252	0.014	0.622	-0.539	0.091	0.194	0.152	0.209	-0.03
TDF						1	0.449	-0.035	0.43	0.361	0.334	-0.041	-0.143	-0.094	0.448	-0.179	-0.126	-0.001	-0.061	-0.083	-0.212
L*							1	-0.669	0.632	-0.122	0.85*	0.421	0.145	0.56	-0.482	0.297	-0.7	-0.867*	-0.875*	-0.872*	-0.879*
a*								1	0.08	-0.327	-0.256	0.156	0.314	-0.03	0.653	-0.53	0.781	0.849*	0.833*	0.718	0.758
b*									1	-0.457	0.859*	0.589	0.515	0.659	0.012	-0.093	0	-0.3	-0.294	-0.552	-0.286
BD										1	-0.566	-0.863*	-0.879*	-0.783	0.428	-0.162	0.085	0.186	0.2	0.244	0.201
D4,3											1	0.72	0.606	0.779	-0.438	0.275	-0.489	-0.673	-0.694	-0.792	-0.709
WHC												1	0.646	0.943**	-0.369	-0.054	-0.256	-0.367	-0.383	-0.309	-0.449
OHC													1	0.527	-0.371	0.428	-0.137	-0.132	-0.181	-0.326	-0.192
WSC														1	-0.435	-0.077	-0.256	-0.525	-0.505	-0.491	-0.504
GAC															1	-0.754	0.791	0.827*	0.831*	0.712	0.755
SCBC																1	-0.704	-0.538	-0.592	-0.592	-0.543
CBC																	1	0.849*	0.901**	0.677	0.943**
TPC																		1	0.992**	0.906*	0.936**
DPPH																			1	0.897*	0.969**
NO																				1	0.803**
ORAC																					1

PC: protein content; FC: fat content; AC: ash content; MC: moisture content; TC: Total carbohydrate; BD: bulk density; WHC: water holding capacity; OHC: oil holding capacity; WSC: water swelling capacity; GAC: glucose adsorption capacity; SCBC: sodium cholate binding capacity; CBC: cholesterol binding capacity; TPC: total phenolic content; DPPH: 2,2-diphenyl-1-picrylhydrazyl scavenging activity; NO: nitric oxide radical scavenging activity; ORAC: oxygen radical absorbance capacity. * $p < 0.05$; ** $p < 0.01$.

CONCLUSIONS

- All studied samples were found to be rich in dietary fiber (49.1 – 65.4%), while low in protein (3.9 – 13.9%), ash (2.23 – 5.03%), and fat (0 – 0.71%), highlighting their potential as a fiber-rich ingredient source.
- Chickpea hull displayed the highest water/oil holding (5.91 g/g and 1.48 g/g), and water swelling (4.17 mL/g) capacities, making it suitable for improving texture and mouthfeel in food formulations.
- Red lentil hull exhibited the highest glucose adsorption (308.0 mg/g) and exceptional cholesterol binding (135.2 mg/g) capacities, while cowpea hull exerted the greatest sodium cholate binding capacity (29.9 mg/g). These findings underscore their potential in glycemic and lipidemic control.
- Colored hulls (red lentil, faba bean, black bean, cowpea) demonstrated significantly higher total phenolic content (8.5 – 35.7 mg gallic acid equivalent (GAE)/g) with the highest value for red lentil, as opposed to the light-colored chickpea and yellow pea hulls (< 1 mg GAE/g).
- Antioxidant activities, as assessed by DPPH•, NO•, and ORAC assays, positively correlated with phenolic content ($r = 0.992$, 0.906, and 0.936, respectively, $p < 0.05$).