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Coffee Pulp Valorization Strategy: flavonoid- and lipid-enriched food-grade ingredients obtained from an advanced extraction technology

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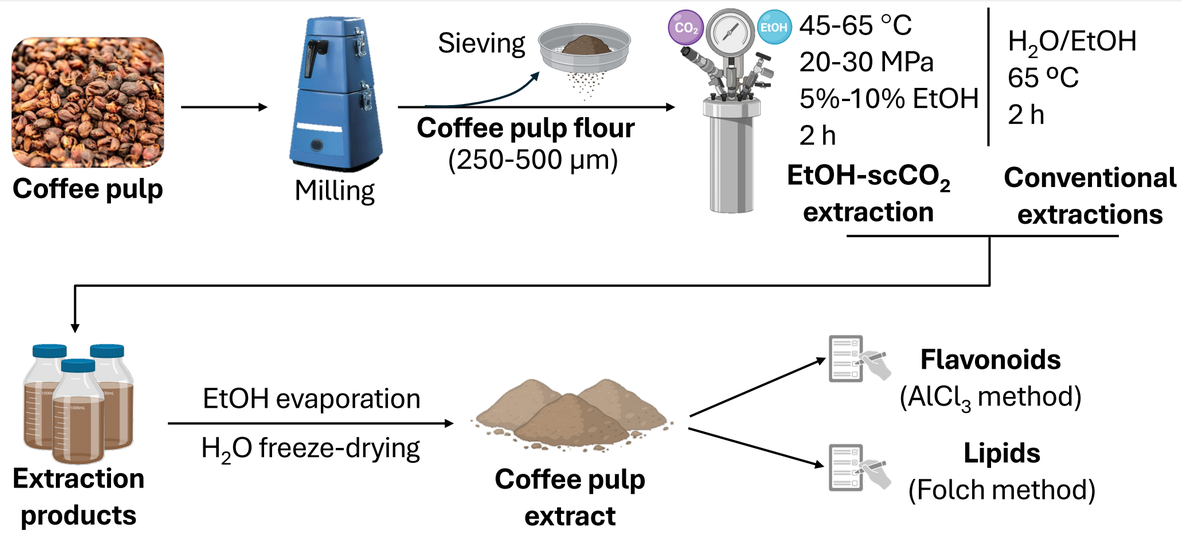
Introduction & Aim

The **valorization of coffee pulp** (CP) is gaining interest because of its content in high-value bioactive compounds. **Flavonoids and lipids** have been traditionally recovered from coffee by-products using organic solvents such as methanol, hexane, or acetone [1]. However, the toxicity of these solvents limits their food applications. Accordingly, the development of food-grade extraction processes is promoted, supporting the idea of sustainability [2].

This work investigated the feasibility of **ethanol-modified supercritical carbon dioxide (EtOH-scCO$_2$) extraction** as a safe and green technique for recovering flavonoids and lipids from CP. The extraction conditions were screened by response surface methodology to **maximize selectivity** (per unit of extract) and **efficiency** (per unit of CP) of lipid and flavonoid recovery.

Method



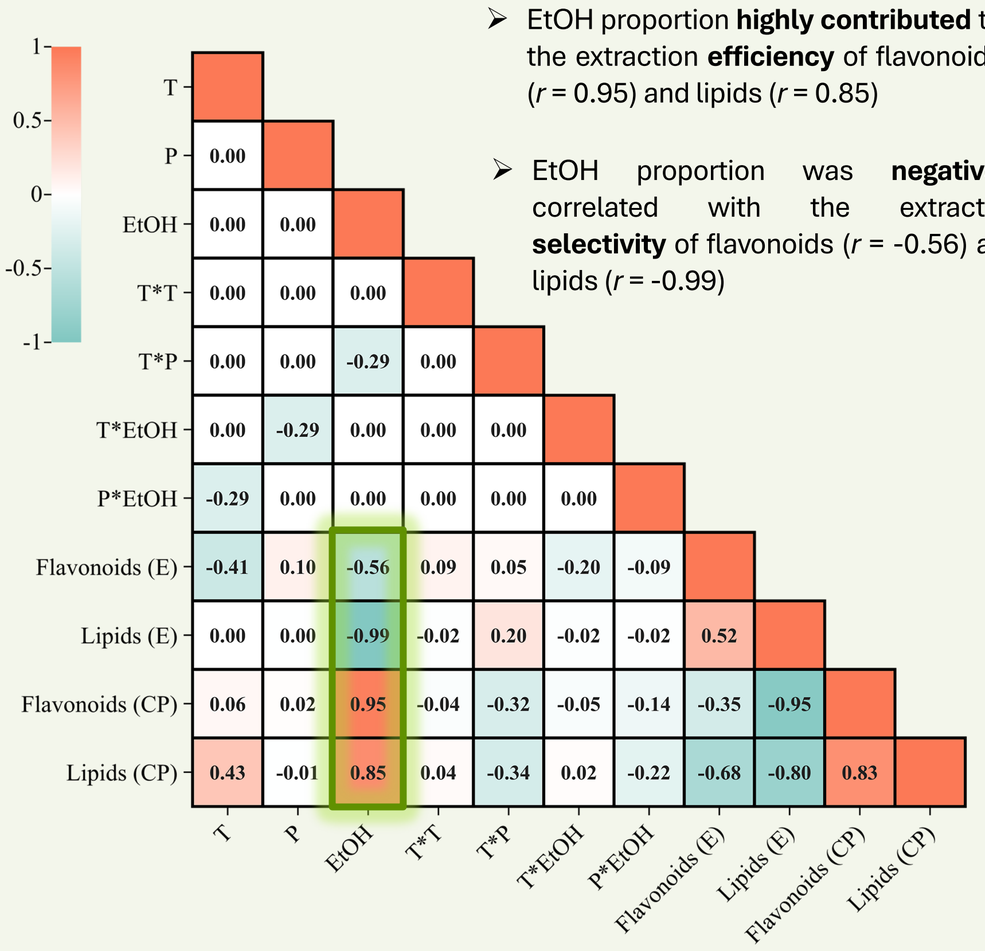
Results & Discussion

Table 1. Experimental data of the response variables

Sample	Factors			Response variables expressed per unit of extract		Response variables expressed per unit of CP	
	T (ºC)	P (MPa)	EtOH (w/w, %)	Flavonoids (µg CE/mg)	Lipids (mg/g)	Flavonoids (µg CE/mg)	Lipids (mg/g)
N1	45	20	5	33.3 ± 1.3^{g}	466.9 ± 17.0^{d}	0.9 ± 0.0^{ab}	12.9 ± 0.5^{ab}
N2	45	30	10	29.1 ± 1.0^{def}	345.2 ± 7.7^{c}	1.4 ± 0.1^{de}	17.9 ± 0.4^{gh}
N3	45	30	5	**33.7 ± 2.9^{g}**	483.7 ± 23.6^{d}	0.9 ± 0.0^{ab}	13.2 ± 0.7^{b}
N4	45	20	10	27.7 ± 0.6^{cde}	328.2 ± 3.7^{c}	1.4 ± 0.1^{d}	17.7 ± 0.2^{gh}
N5	45	20	5	31.7 ± 1.7^{fg}	476.5 ± 31.1^{d}	0.9 ± 0.0^{ab}	13.4 ± 0.9^{b}
N6	55	20	10	31.8 ± 1.7^{fg}	308.2 ± 7.5^{c}	1.7 ± 0.0^{e}	17.2 ± 0.5^{fgh}
N7	55	20	5	26.9 ± 2.0^{bcd}	493.5 ± 1.6^{d}	0.7 ± 0.0^{a}	14.2 ± 0.1^{bc}
N8	55	30	10	27.6 ± 1.0^{cde}	318.6 ± 6.4^{c}	1.6 ± 0.0^{de}	18.3 ± 0.4^{gh}
N9	55	30	5	30.4 ± 1.2^{efg}	**505.3 ± 10.2^{d}**	0.9 ± 0.0^{ab}	15.5 ± 0.3^{cde}
N10	65	30	10	23.7 ± 1.5^{b}	309.4 ± 8.2^{c}	1.4 ± 0.1^{cd}	18.7 ± 0.5^{hi}
N11	65	30	5	29.6 ± 0.7^{def}	468.3 ± 16.9^{d}	0.9 ± 0.0^{ab}	15.0 ± 0.6^{cd}
N12	65	20	10	25.4 ± 1.5^{bc}	319.4 ± 8.3^{c}	1.5 ± 0.1^{de}	20.0 ± 0.5^{ij}
N13	65	20	5	30.9 ± 1.5^{efg}	492.6 ± 1.2^{d}	0.9 ± 0.1^{ab}	15.3 ± 0.1^{cd}
N14	45	30	10	31.7 ± 2.5^{fg}	316.6 ± 11.5^{c}	1.6 ± 0.1^{de}	17.0 ± 0.6^{efg}
N15	65	30	5	33.6 ± 0.8^{g}	479.0 ± 6.7^{d}	1.1 ± 0.1^{bc}	15.9 ± 0.2^{def}
N16	65	20	10	26.9 ± 1.6^{bcd}	347.1 ± 17.4^{c}	1.6 ± 0.1^{de}	21.4 ± 1.1^{j}
Water				17.0 ± 0.8^{a}	30.0 ± 2.4^{a}	**6.6 ± 0.2^{g}**	11.6 ± 0.7^{a}
Ethanol				16.6 ± 1.1^{a}	136.7 ± 8.2^{b}	3.6 ± 0.1^{f}	**29.8 ± 0.2^{k}**

$^{a-k}$ Different superscript letters indicate statistically significant differences at $p < 0.05$ within the same response.

- Compared to conventional water and ethanol extractions, **EtOH-scCO$_2$ yielded lower flavonoid recovery efficiency;** while the **opposite was observed for lipids** compared to water extraction.
- A superior extraction selectivity was achieved using EtOH-scCO$_2$ compared to conventional extractions, up to 33.7 mg CE/g extract for flavonoids at **45 °C, 30 MPa, and 5% ethanol**; and 505.3 mg/g extract for lipids at **55 °C, 30 MPa and 5% ethanol**.



- EtOH proportion **highly contributed** to the extraction **efficiency** of flavonoids (r = 0.95) and lipids (r = 0.85)
- EtOH proportion was **negatively** correlated with the extraction **selectivity** of flavonoids (r = -0.56) and lipids (r = -0.99)

Figure 1. Heatmap of correlation among factors and response variables including their corresponding Pearson correlation coefficients

- EtOH significantly ($p < 0.05$) **increased** the extraction **efficiency** (regression coefficients=0.31 and 0.20 for flavonoids and lipids, respectively) but **decreased** the extraction **selectivity** (regression coefficients=-1.75 and -8.17 for flavonoids and lipids, respectively). Similar effects were observed for temperature, although they lacked statistical significance ($p > 0.05$).
- **Interactions** between factors were observed, but no significant ($p > 0.05$) effects were noted.

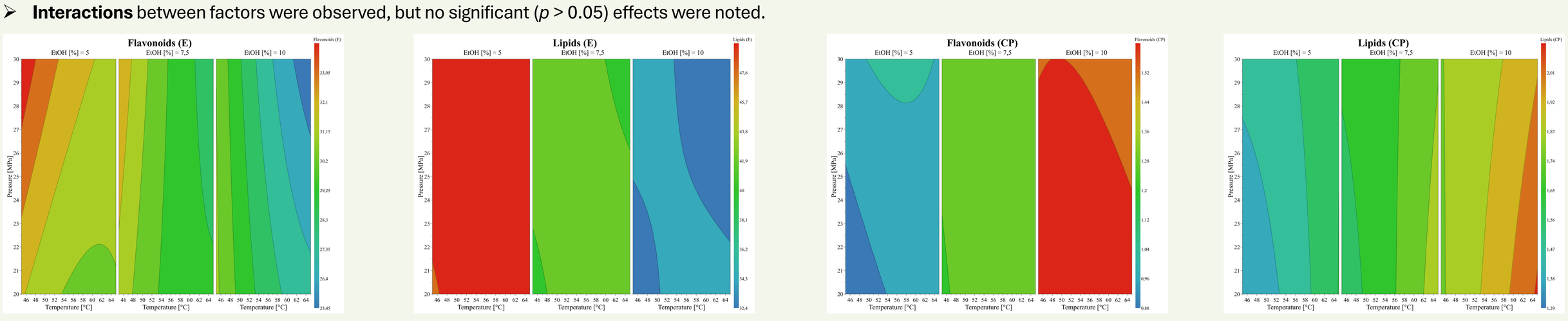


Figure 2. Response contour plots showing the impact of temperature, pressure and co-solvent on the response variables.

Conclusion

The increased amount of **ethanol** as a co-solvent **enhanced the extraction efficiency** but reduced selectivity **for flavonoids and lipids**, which might be attributed to the modification in polarity of the system induced by the mentioned co-solvent.

The **selectivity** results indicate that **EtOH-scCO$_2$** appears to be a **promising technique** for obtaining flavonoid- and lipid-enriched food-grade ingredients from coffee pulp, compared to the conventional extractions.

Further research is needed to clarify the potential applications of flavonoid- and lipid-enriched CP extracts to valorize coffee industry by-products as bioactive food-grade ingredients.

References

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