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UAV Canopy Height Models and Vegetation Indices for Assessing Yield and Stress Traits in Spring Wheat Breeding

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INTRODUCTION

High-throughput phenotyping (HTP) is a key tool in modern wheat breeding, enabling rapid, large-scale, and non-destructive trait assessment. UAV-based HTP with multispectral and RGB sensors allows monitoring of canopy growth, architecture, and stress responses. Trait associations can vary across environments and growth stages; drought, lodging, and phenological differences (especially days to heading, DH) can confound spectral measurements.

The aim of research: Assess the consistency of vegetation indices (VIs) and UAV canopy height models (CHM) for predicting grain yield (GY) in spring wheat, accounting for phenology and stage-dependent growth dynamics.

MATERIALS AND METHODS

- **Field trials:** AREI Stende Research Centre, Latvia, 2021–2022; 300 spring wheat genotypes in 5 m² plots with two replications.
- **Weather:** 2021 – hot, drought stress; 2022 – cooler, wetter, more lodging.
- **Field traits:** Plant height (PH), days to heading (DH), grain yield (GY), drought tolerance (DT, 2021; 1 = high, 5 = low), lodging resistance (LR, 2022; 1 = lodged, 9 = no lodging).
- **DH groups (balanced)** – early / middle / late: 2021 – ≤52 / 53 / ≥54; 2022 – ≤63 / 64 / ≥65.
- **UAV phenotyping:** Phantom 4Pro with multispectral camera at 20 m; vegetation indices (NDVI, NGRDI, NDRE) calculated from **mid-milk stage (GS75)**.
- **CHM:** Difference between digital surface and terrain models; measured mid-season (07.07) in 2021, and mid-season (30.06) and late-season (12.08) in 2022.

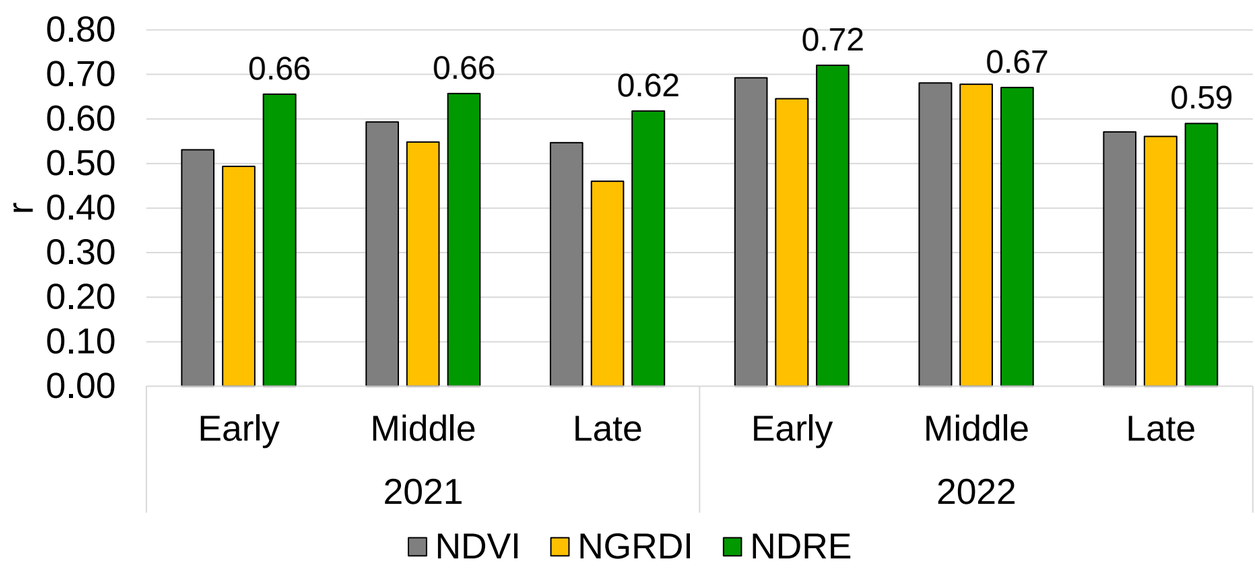
RESULTS

Correlation coefficients between UAV-derived vegetation indices and field-measured agronomic traits

Trait	NDVI	NGRDI	NDRE
2021			
Grain yield	0.55***	0.51***	0.65***
Days to heading	0.58***	0.60***	0.51***
Drought tolerance	-0.21***	-0.19***	-0.24***
Lodging resistance	0.02	-0.12**	0.09*
Plant height	0.20***	0.23***	0.22***
2022			
Grain yield	0.64***	0.62***	0.66***
Days to heading	0.29***	0.32***	0.25***
Lodging resistance	0.10*	0.05	0.13**
Plant height	-0.03	0.00	-0.05

* p<0.05; **p<0.01; ***p<0.001

Effect of early, middle, and late heading groups on UAV vegetation index–grain yield correlations (2021–2022)



Early = ≤52 (2021) / ≤63 (2022), Middle = 53 / 64, Late = ≥54 / ≥65

UAV CHM correlations with manual plant height (PH) and lodging resistance (LR) at mid- and late growth stages

Stage	Trait	r	Interpretation
2021			
Mid-season	CHM vs. PH	0.47***	UAV CHM reflects plant height well
2022			
Mid-season	CHM vs. PH	0.55***	UAV CHM reflects plant height well
	CHM vs. LR	-0.37***	Taller canopies start showing slight lodging tendency
Late season	CHM vs. PH	0.16**	Weak correlation - canopy height signal affected by lodging and senescence
	CHM vs. LR	0.62***	Strong correlation - UAV CHM effectively captures lodging severity

**p<0.01; ***p<0.001

Field trial of spring wheat in 2021 at milk growth stage

CONCLUSION

- UAV vegetation indices (VIs), particularly **NDRE**, were strongly associated with grain yield (GY) across years.
- **Grouping by phenology (days to heading, DH)** reduced stage-related variability and strengthened VI–GY relationships, especially in early and middle DH groups.
- UAV canopy height models (CHM) captured **plant height mid-season** and **lodging late-season**, demonstrating stage-dependent utility.
- VIs detected **drought effects in 2021** (weak negative correlations with drought tolerance), which may partly reduce VI–GY relationships under stress.
- **Seasonal differences** between 2021 (drier, warmer) and 2022 (cooler, wetter) **influenced correlation strengths**, highlighting environmental effects on UAV-based phenotyping.
- **Phenology-aware, multi-temporal UAV phenotyping** provides robust, non-destructive assessment of yield and stress traits, supporting efficient wheat breeding.

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