Estimation of the average wheat ear size and ear density at the microplot level from RGB images: characterizing the variability of yield components from high-throughput plant phenotyping

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Estimation of the average wheat ear size and ear density at the microplot level from RGB images to characterize the variability of yield components

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BACKGROUND AND OBJECTIVES

Different works have succeeded in using deep learning algorithms such as CNN (Convolutional Neural Networks) for ear counting and ear density estimation in RGB images. However, the use of such techniques to estimate ear morphological traits, such as ear area, has not yet been explored. The objectives of this study are:

(i) To evaluate against field measurements **a novel method that combines CNN** for object detection and segmentation **with a physical model to estimate** automatically **ear density and the average ear size.**

(ii) To analyse the variability of the estimated ear density and average ear size **due to G and E over a panel of 10 wheat varieties** in different environments

(iii) To investigate the possible **relationship** between ear density and ear size **with yield and yield components**

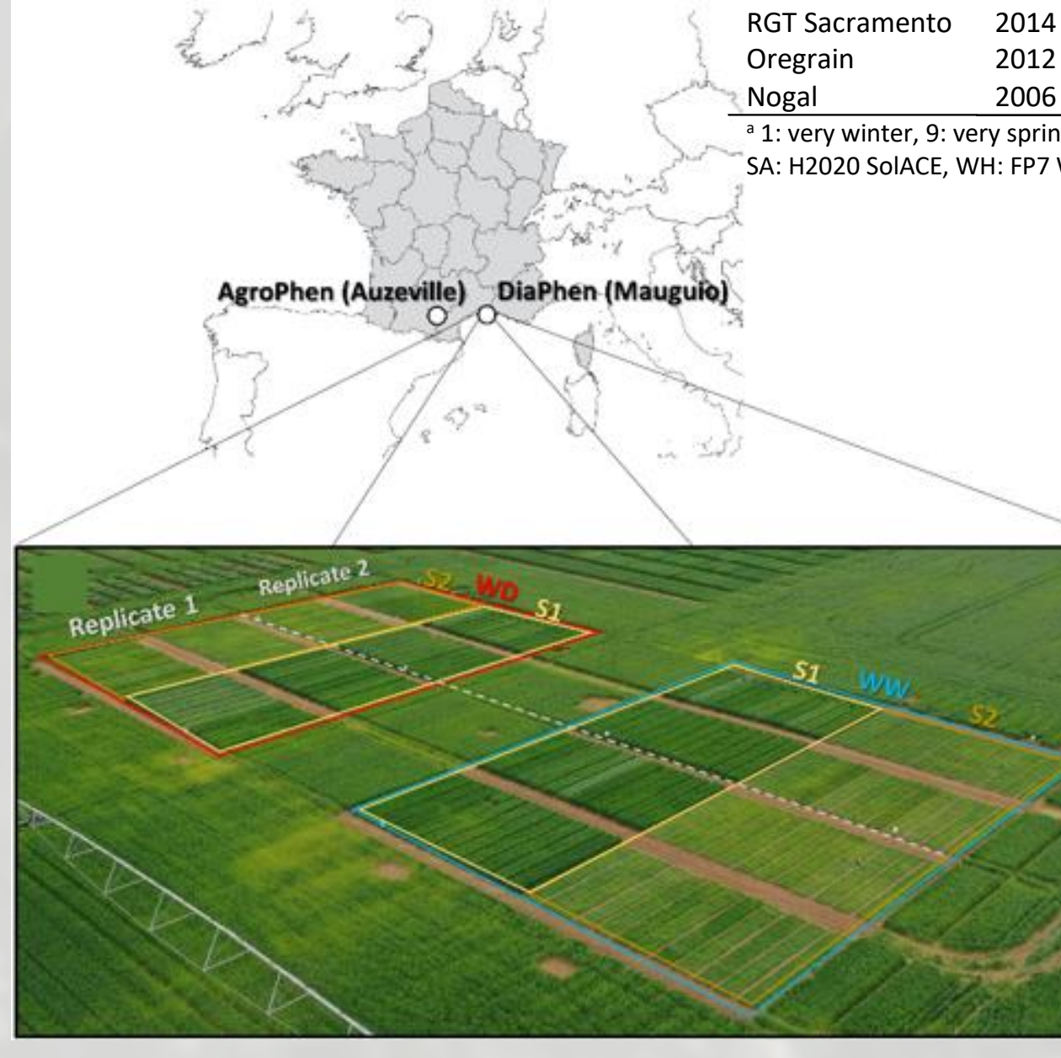
MATERIALS & METHODS

a) Field experiments

Three fields experiments were conducted in SE France (DiaPhen phenotyping plantform at Mauguio in 2022 and 2023; AgroPhen phenotyping platform at Auzeville in 2023) **with a panel of 10 elite bread wheat cultivars**. **Two environmental factors** were tested **on each site**: autumn/winter sowing and rainfed (WD) / irrigated (WW) in DiaPhen; autumn/winter sowing and low (D200) and high (D400) seedling density at AgroPhen.

Cultivar	Registration year	Cold requirement[a]	Precocity at stem extension[b]	Precocity at heading[b]	Height[c]	Awn	Genetic panel[d]
Renan	1990	1	1	6	4	Yes	WH
Fructidor	2014	2	3	6	3.5	Yes	BW
Rubisko	2012	3	3	6.5	3	No	BW, SA, IN
Nemo	2015	3	3	6.5	3.5	Yes	BW
LG Absalon	2016	3	3	6.5	3.5	No	SA, IN
Chevignon	2017	3	2	6	4	No	IN
Apache	1998	4	3	7	3.5	No	BW, SA, IN, WH
RGT Sacramento	2014	4	6	6.5	3.5	Yes	IN
Oregrain	2012	5	4	7	3.5	No	BW, SA, IN
Nogal	2006	8	5	8	3.5	Yes	BW, SA, IN

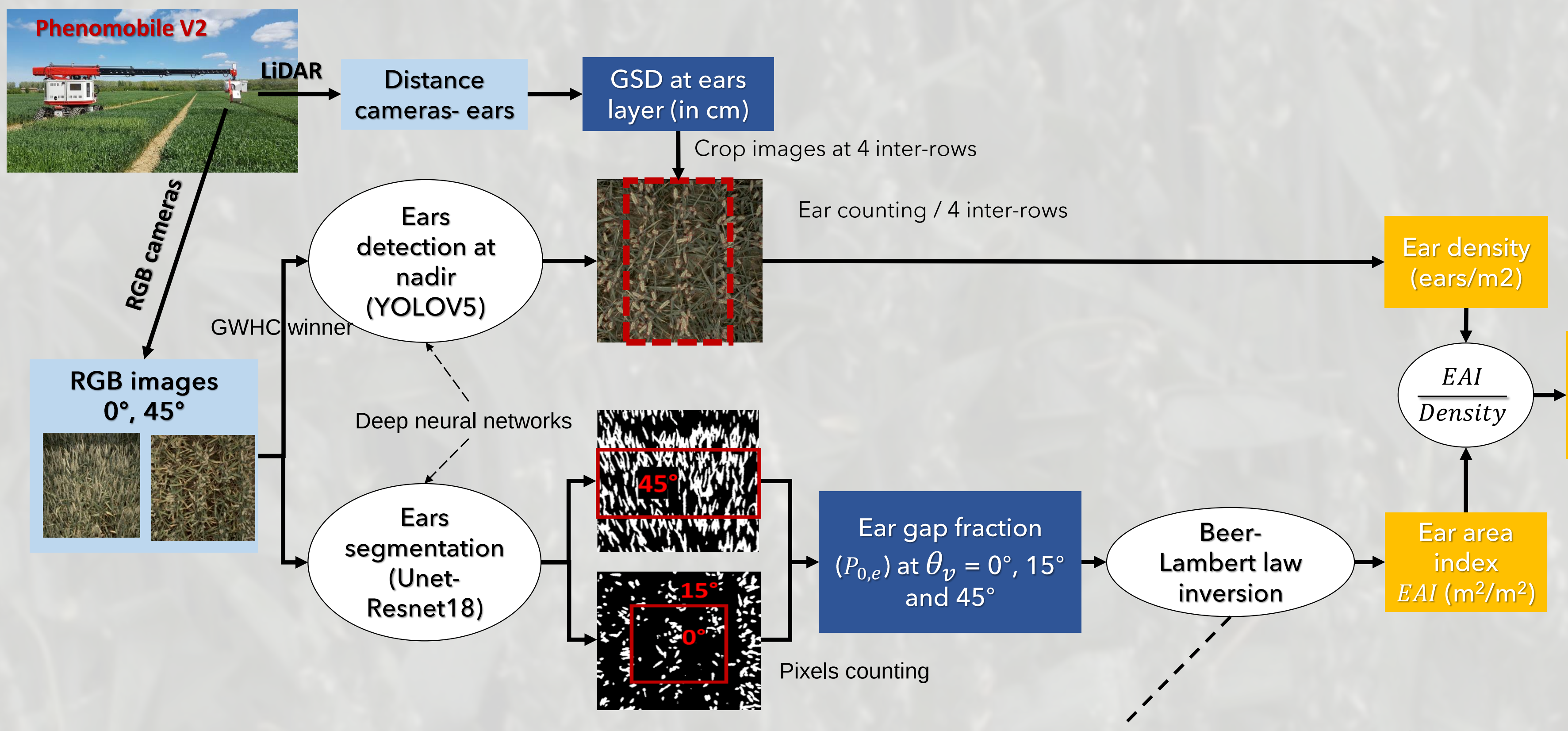
[a] 1: very winter, 9: very spring; [b] 1: late, 9: early; [c] 1: very short, 9: very tall; [d] included in previous projects: BW: ANR PIA Breedwheat, SA: H2020 SolACE, WH: FP7 Whealbi, IN: H2020 INVITE.



The **destructive measurements** for ear density and ear size were **conducted at harvest**, by sampling of 0.65 m^2

- **Ears were counted and cut** on a subsample of 30% of total biomass
- **The average ear size** (vertical cross-section, in cm^2) **was measured** on the 30% subsample **with the Li-Cor 3100**

b) Method to estimate ear density and ear size



Distance cameras- ears

GSD at ears layer (in cm)

Crop images at 4 inter-rows

Ear counting / 4 inter-rows

Ears detection at nadir (YOLOV5)

RGB images 0°, 45°

Ears segmentation (Unet-Resnet18)

Pixels counting

Ear gap fraction ($P_{0,e}$) at θ_v = 0°, 15° and 45°

Beer-Lambert law inversion

Ear density (ears/m2)

$\frac{EAI}{Density}$

Average ear size (cm^2)

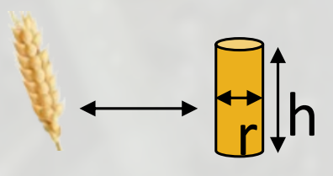
Ear area index EAI (m^2/m^2)

The **method relies on Beer-Lambert Law inversion** using ears gap fraction to solve the following model:

$$P_{0,e}(\theta_v) = e^{-k\left(AEA,\theta_v,\frac{r}{h}\right)*EAI}$$

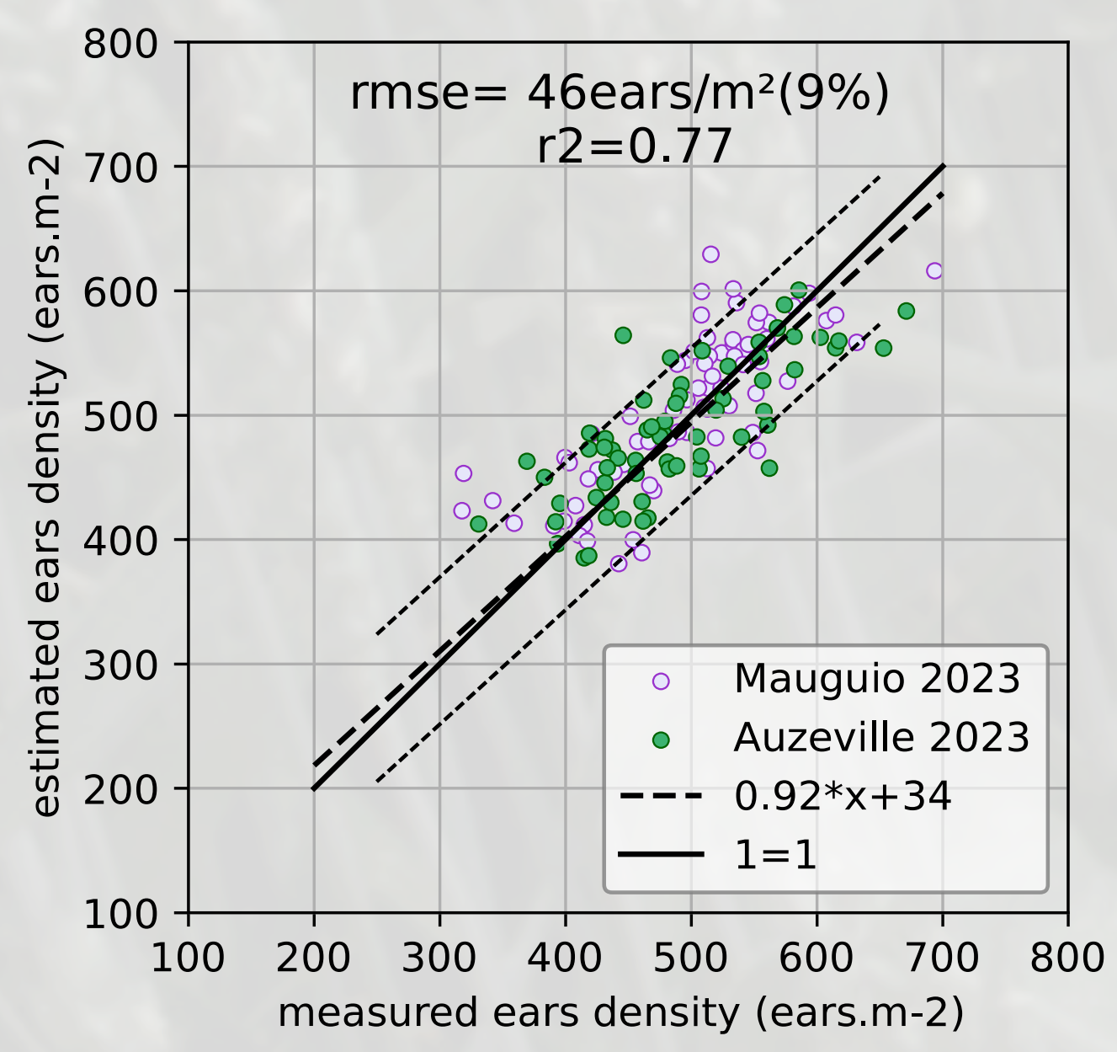
***EAI* is the ear area index (m^2/m^2):** the sum of the area of the vertical cross-section of ears per ground area.

***k* is the extinction coefficient**, computed **from a geometric model where ears are cylinders** inclined following an ellipsoidal distribution defined by the AEA (Average Ear Angle, in °). AEA is optimized to 65° at Zadocks 83 stage



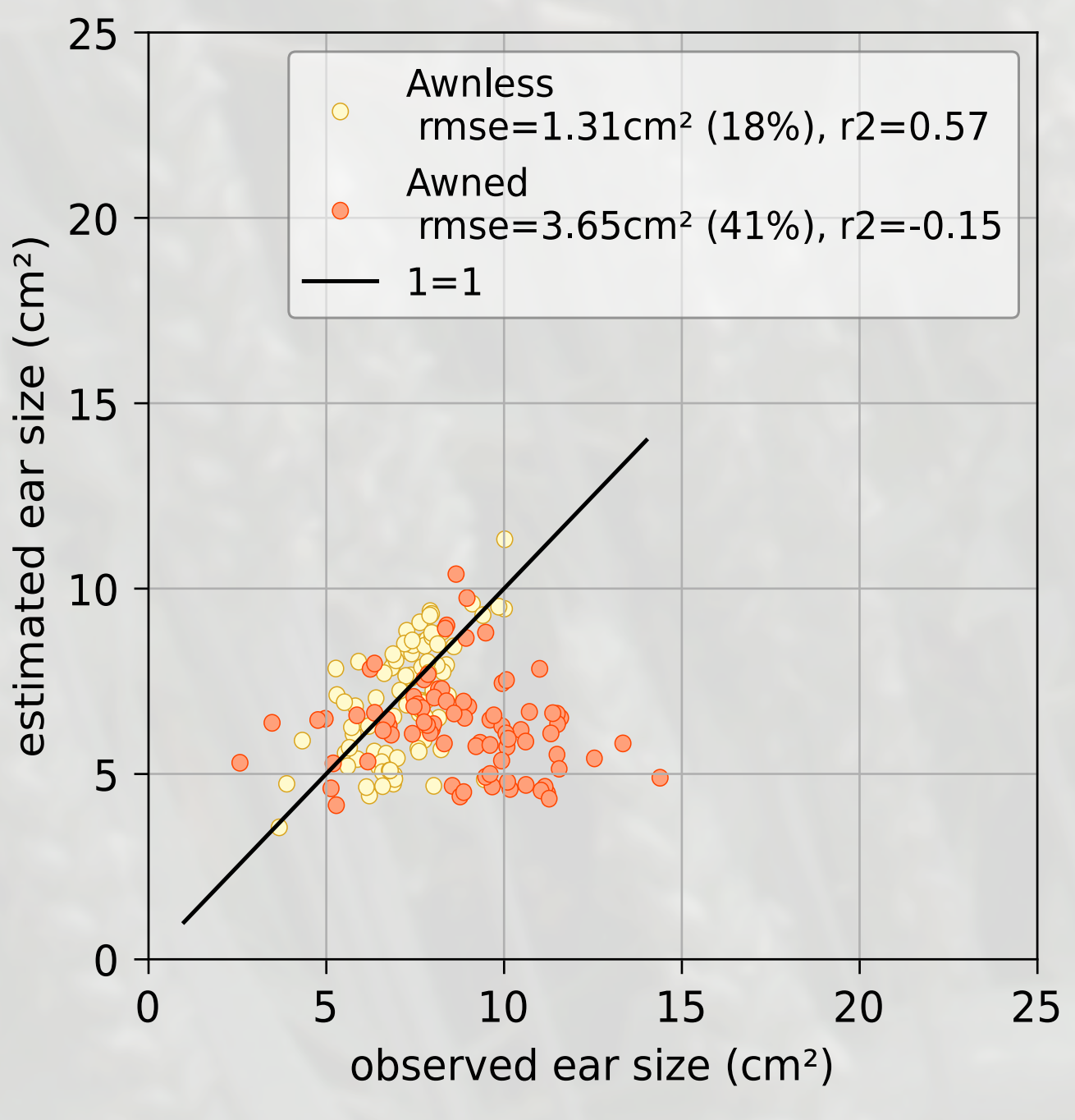
RESULTS

a) Accuracy of ear density and ear size



Ear density is accurately estimated from the object detection algorithm. Absolute **errors are below 10%** and aligned around the 1:1 line.

Repeatability (difference between replicates) **is higher** as compared with **manual measurements**

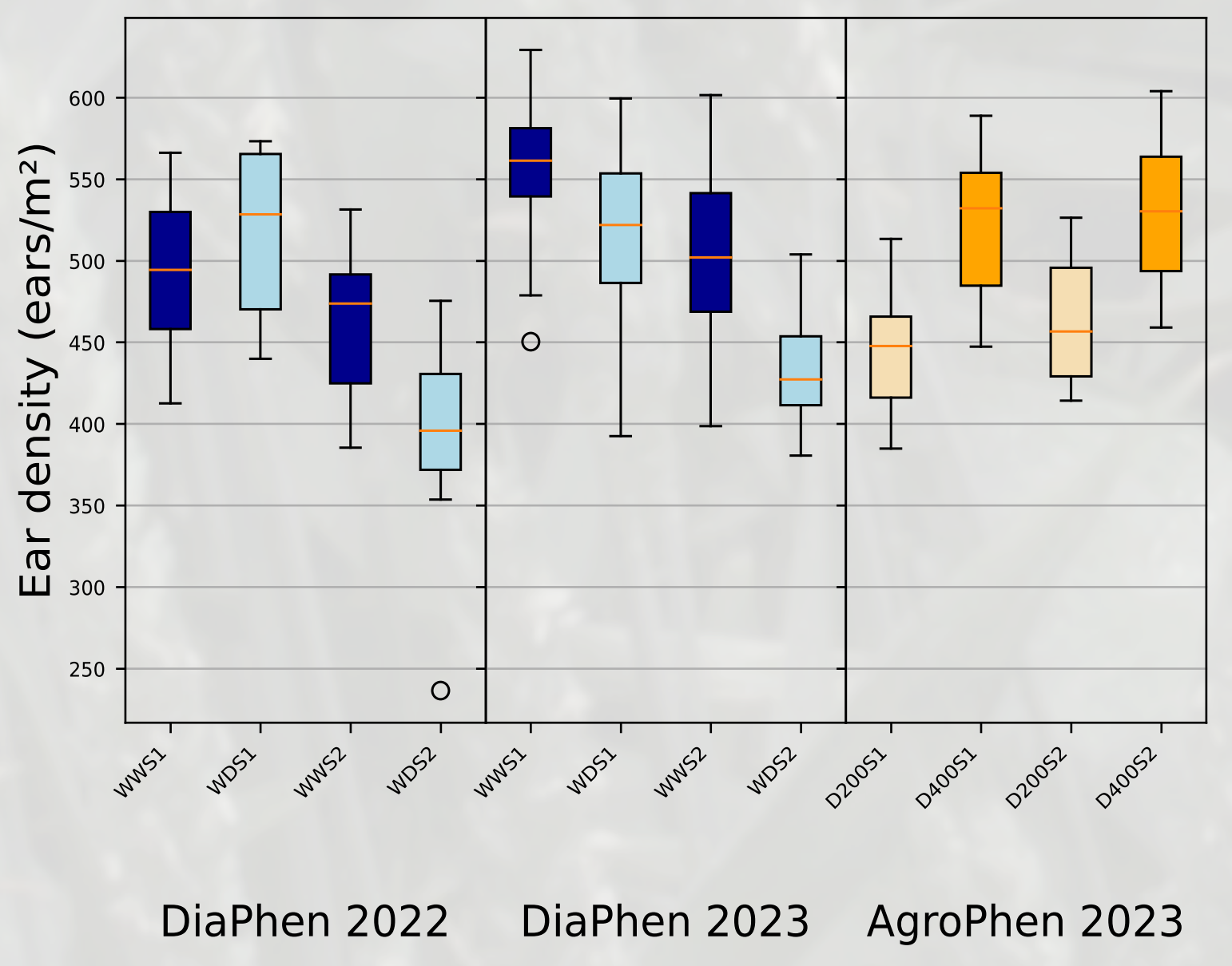


The **average ear size from RGB images agrees** with the Li-Cor 3100 measurements only **for awnless cultivars**

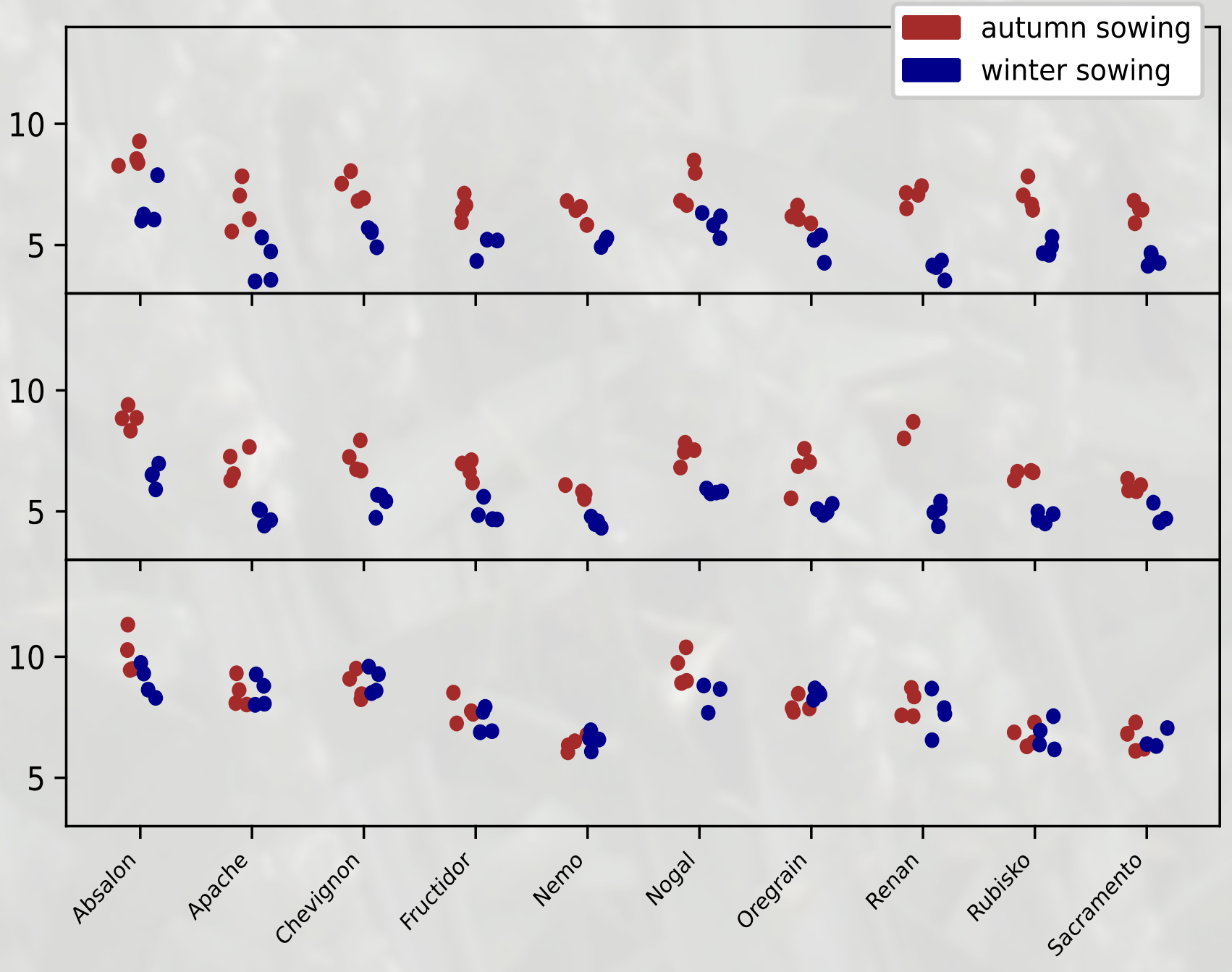
Measurements with Li-Cor 3100 **overestimate the area of awns**, resulting in a **bias for awned cultivars**

The estimation of **ear size from RGB images** (ignoring the area of awns) seems the **most reliable method for awned cultivars.**

b) Variability of estimated ear density and ear size due to GxE



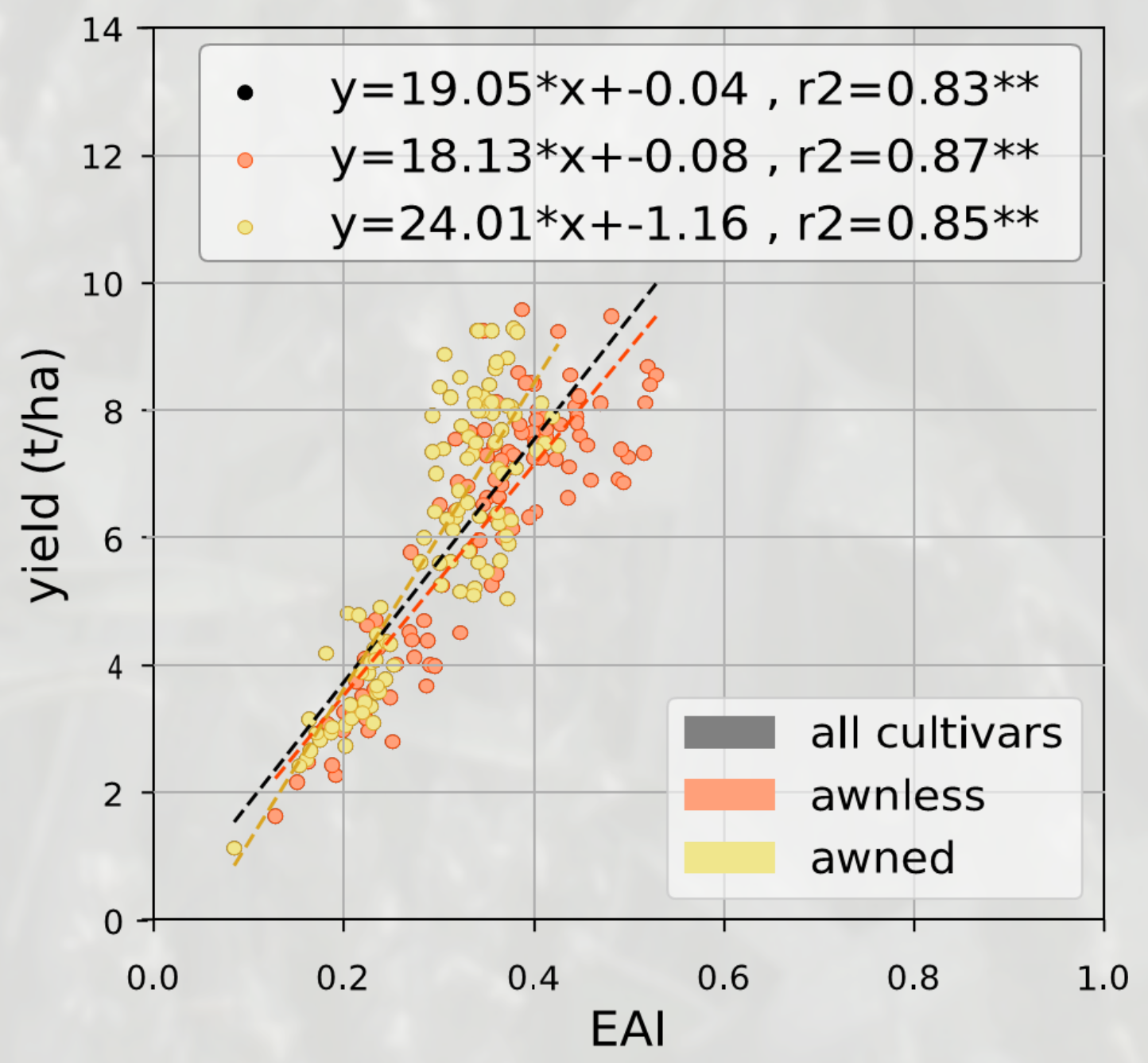
Environmental factors explain 65%-70% of the variance in **ear density** in the three experiments. At the DiaPhen site (Montpellier) the effect of **water stress in winter sowings** produce a drastic reduction in the head density.



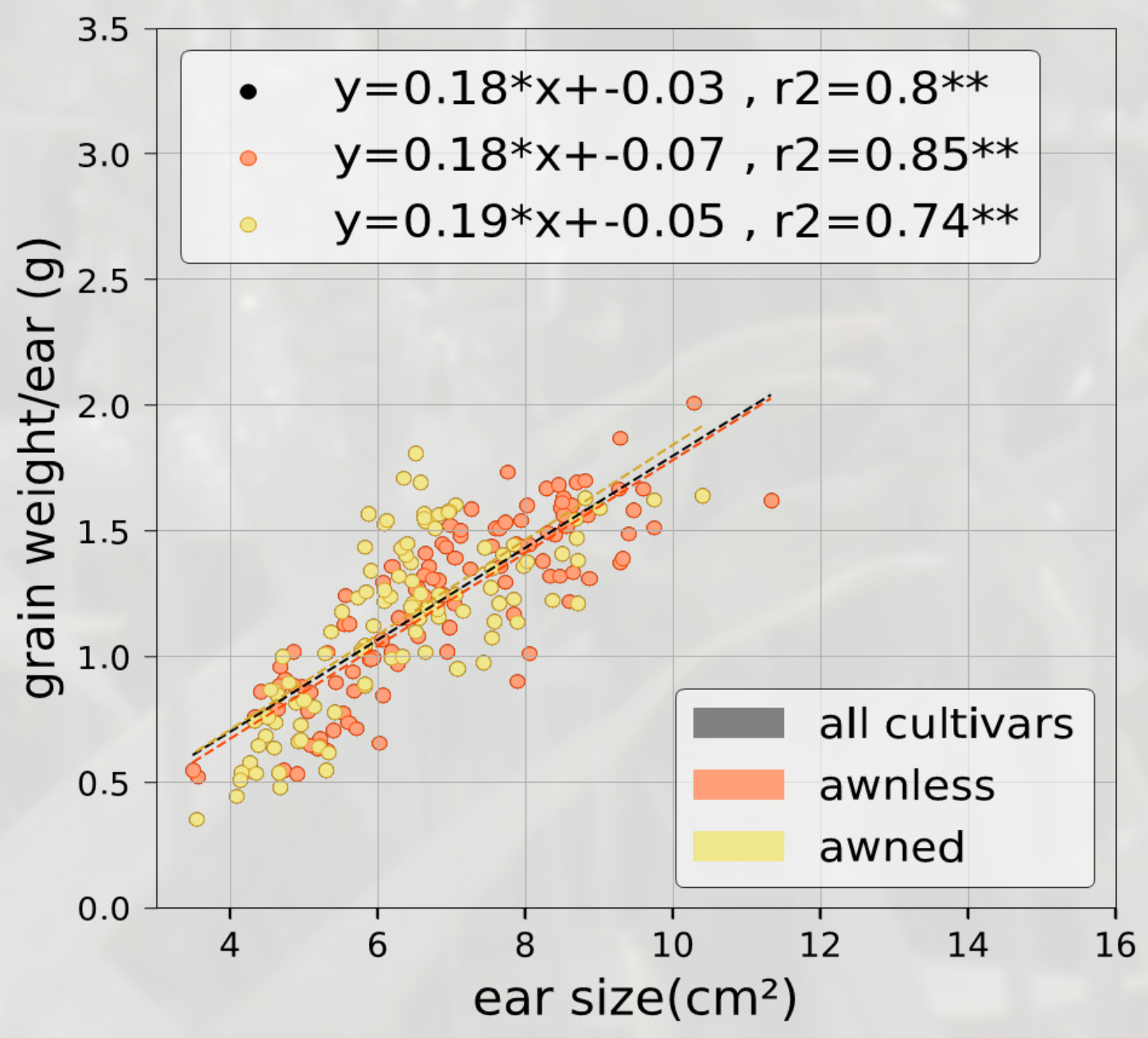
In a **Mediterranean** environment (DiaPhen 2022, 2023) **ear size decreases in very late winter sowings**, correlated with yield

Average **ear size is highly heritable in high-yielding environments** (H^2 = 0.78 at AgroPhen 2023), and coherent with DiaScope autumn sowings

c) Relationship ear size/yield components



The **EAI** estimated from the method proposed **is strongly correlated with yield** for both awnless and awned cultivars. Similarly, the average **ear size is also strongly correlated with the grain weight per ear.** The correlation between ear size and number of grains is weaker (r2=0.47, not shown)



The analysis of the correlations EAI-yield and ear size-grain weight **per genotype indicate slightly different linear models** (r2 ranging from 0.8 to 0.95, not shown) possibly **linked to the ear compactness**.

CONCLUSIONS

In this study, we **proposed an original methodology based on deep learning** algorithms **and** a physical model (**Beer-Lambert law**) **to estimate ear density and ear size** from RGB images. The evaluation of this methodology against manual measurements showed **satisfactory performances for ear density (relative RMSE <10%**). The **ear size** estimation from RGB images is **more reliable than manual measurements** with a reference method (Li-Cor 3100) that produces a bias the ear area **of awned cultivars**. The **strong correlation between** the estimated **ear size and grain weight per ear** (all cultivars) supports the reliability of the proposed method and suggest that Ear Area Index (**EAI) can be a good proxy for yield**.

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