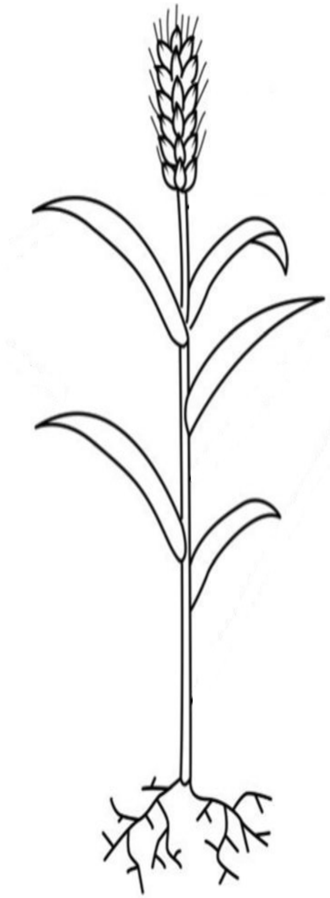
Centro de Mejoramiento Genético y Fenómica Vegetal

TALCA UNIVERSIDAD CHILE

Role of ear contribution to grain filling in C3 cereals

Abdelhalim Khaled Elazab

Grain development in C3 cereals



Is sustained by carbon production from three sources:

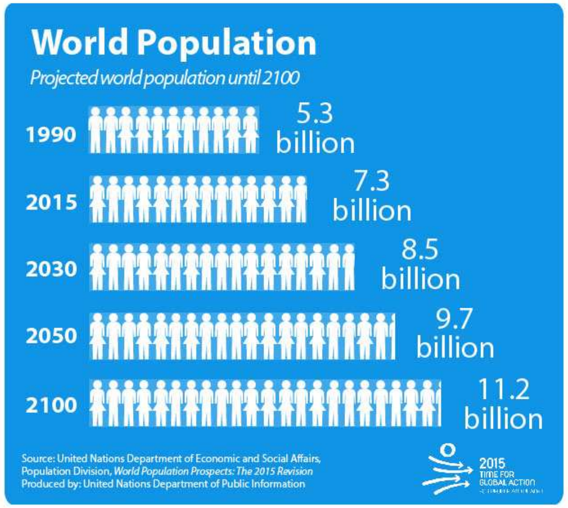
(a) redistribution of assimilates (WSC mainly fructans) stored in the stem (Álvaro et al., 2008; Xiao et al., 2012).

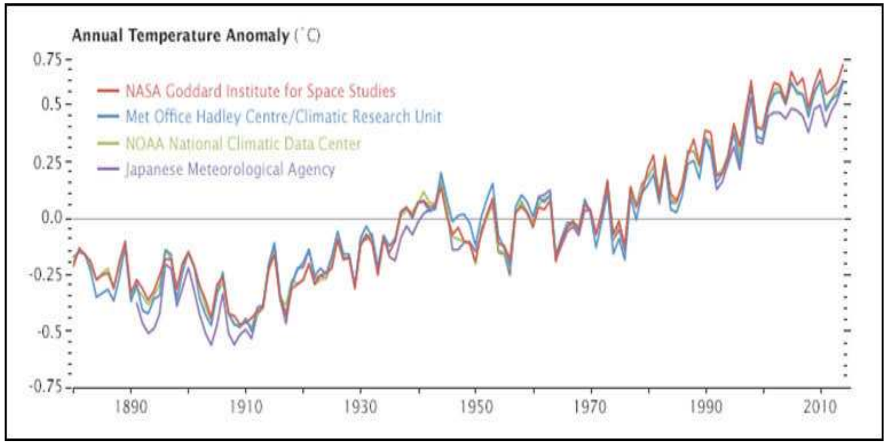
(b) photosynthesis of the flag leaf (Inoue et al., 2004; Tambussiet al., 2007, 2021).

(c) photosynthesis of the ear (Abbad et al., 2004; Araus et al., 1993; Maydup et al., 2010, 2012, 2014; Molero and Reynoldes 2020).

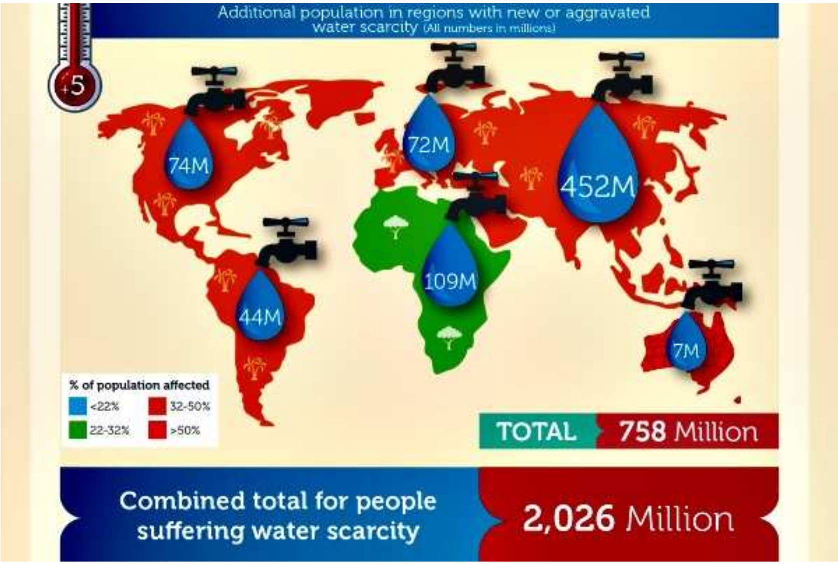
Why enhancing flag leaf and ear photosynthesis is crucial

- Population growth
- Global climate change.
- Green revolution (semi-dwarf alleles / better agronomic practices).
    1. Old genotypes are sink limited.
    2. Modern genotypes are source limited.





NASA 2015



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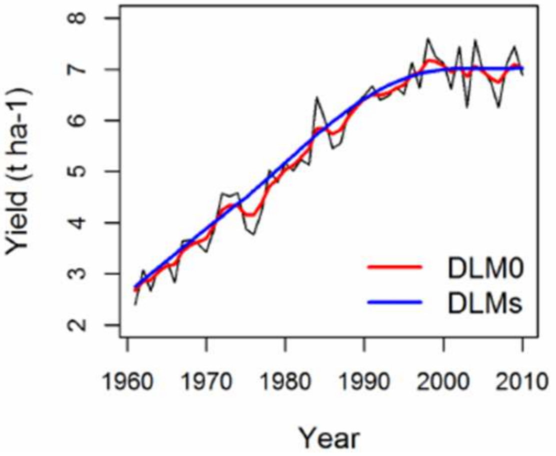
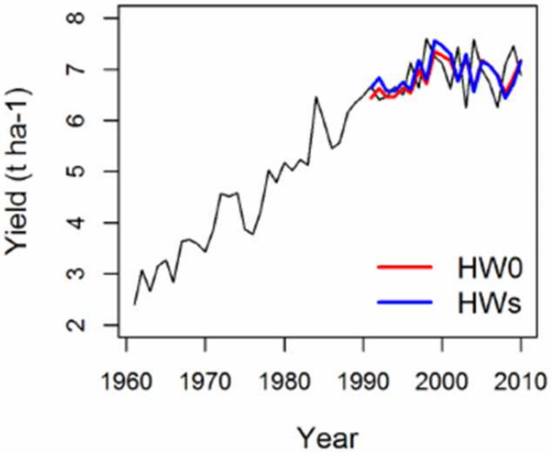
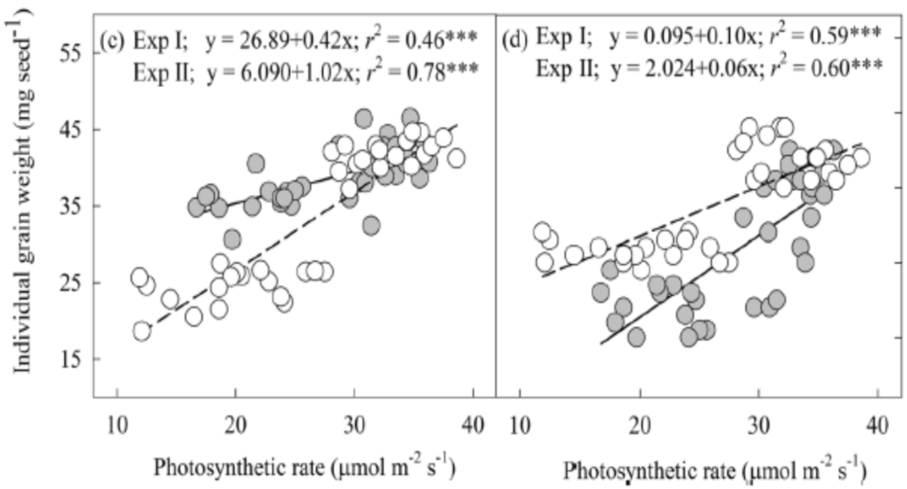
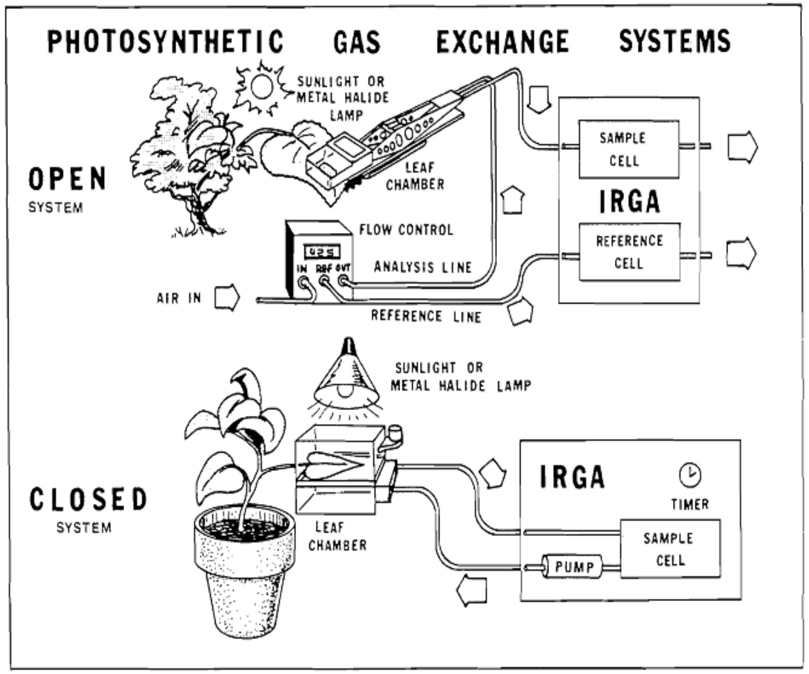


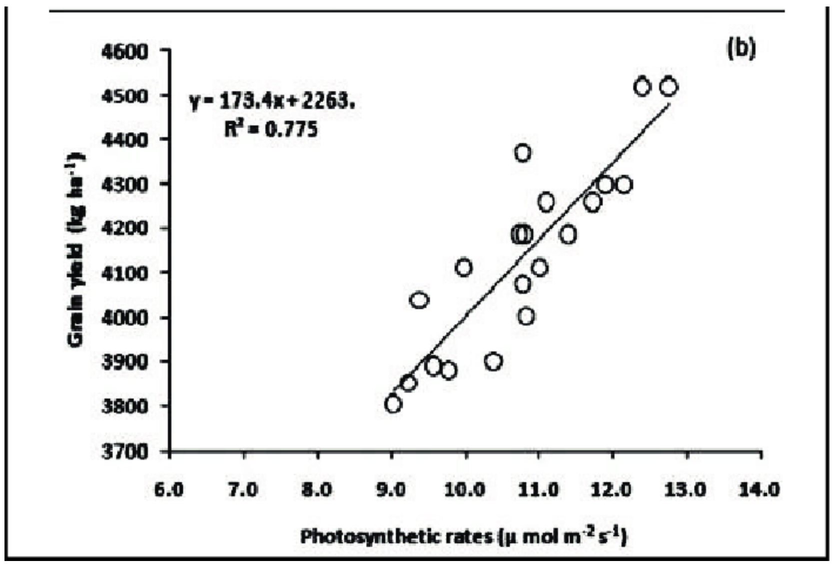


How to measure leaf photosyntheis



Djanaguiraman et al 2020

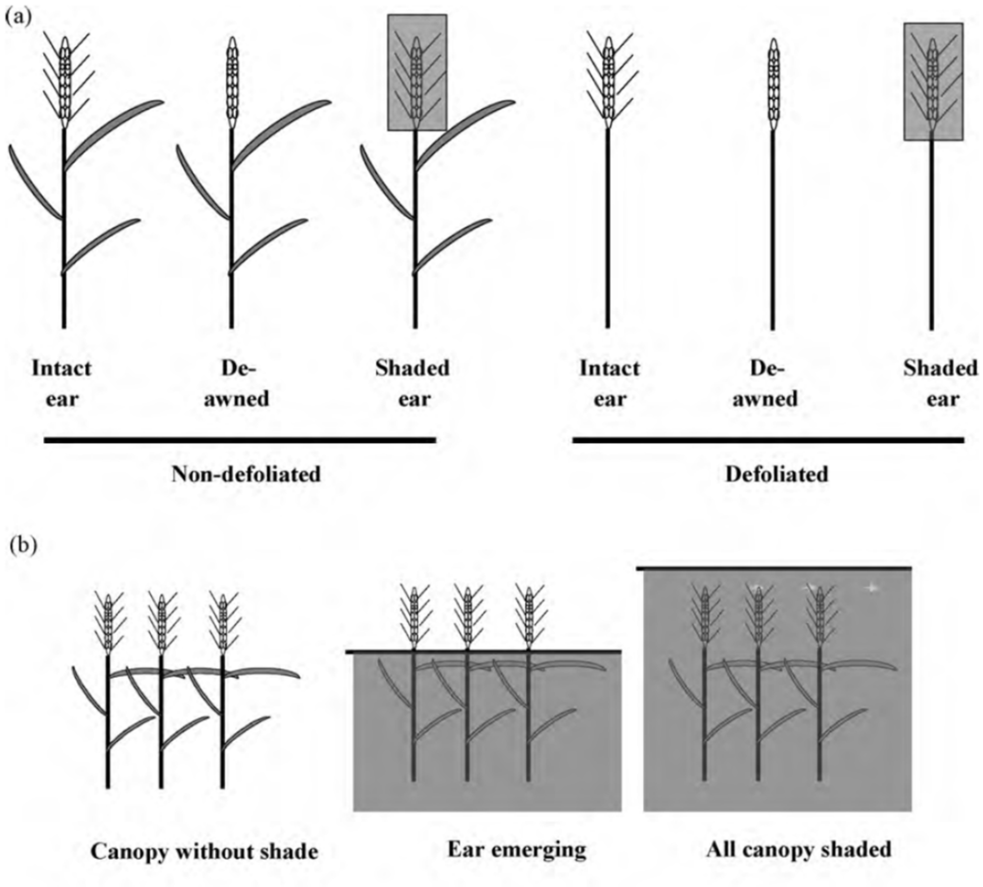




Sharma and Singh 2018

Methodological techniques for studying ear contribution to grain filling

- Source manipulation techniques



Maydup et al 2010

Oragn shadding or removal (Maydup et al 2010, 2012. 2014; Elazab et al 2021)

We calculated the ear contribution to grain filling as:

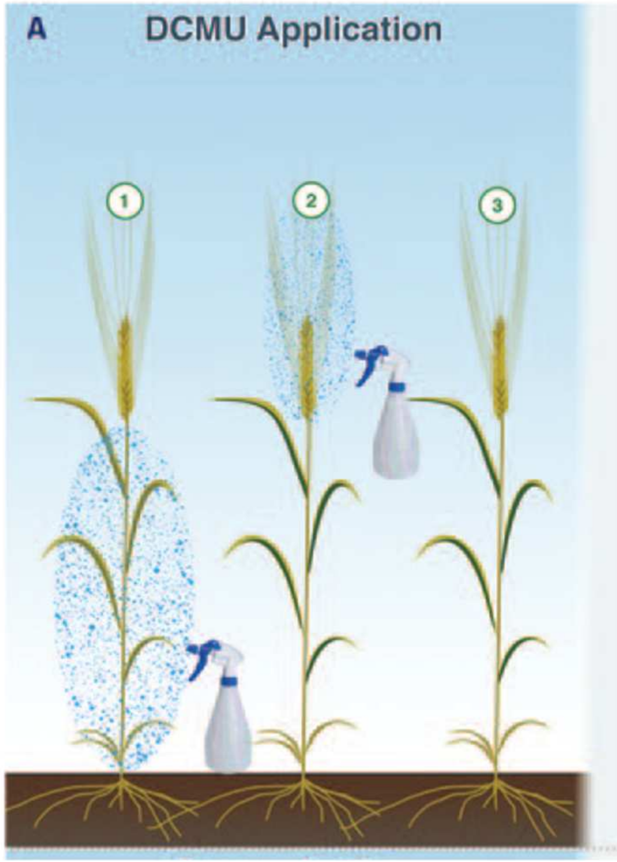
$$\left[\frac{(GW_{ear} \text{ of non shaded ear} - GW_{ear} \text{ of shaded ear}) \times 100}{GW_{ear} \text{ of non shaded ear}}\right]$$

where GW_{ear} is total grain weight per ear.

$$\text{Ear contribution } (\%) = \left[\frac{TKW_{CP} - TKW_{ESP}}{TKW_{CP}}\right] \times 100 \quad (1)$$

Methodological techniques for studying ear contribution to grain filling

- Source manipulation techniques

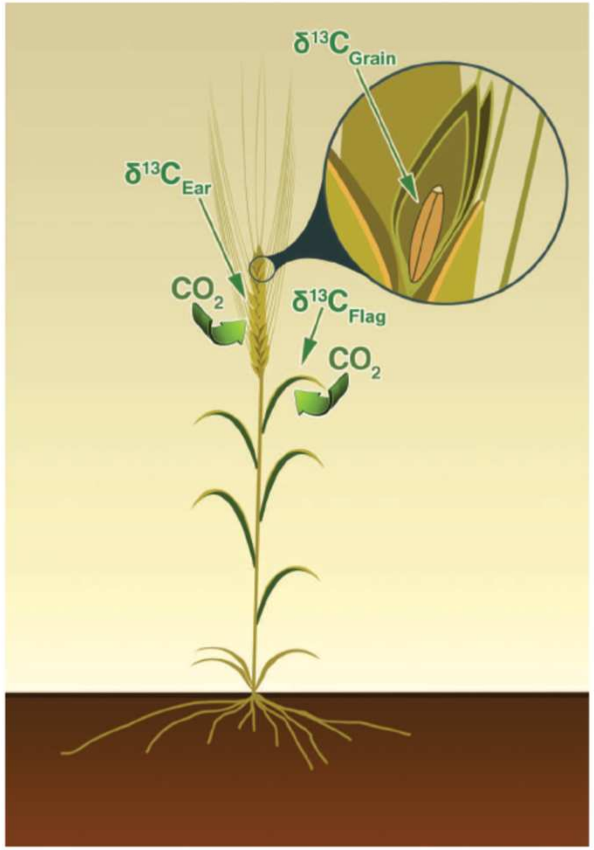


Sanchez et al 2016

a pharmacological approach, inhibiting ear photosynthesis with 3-(3,4-dichlorophenyl)-1,1-dimethylurea
(DCMU) (Maydup et al., 2010; Molero et al., 2014; Sanchez-
Bragado et al., 2016);

Methodological techniques for studying ear contribution to grain filling

- The use of stable isotopes

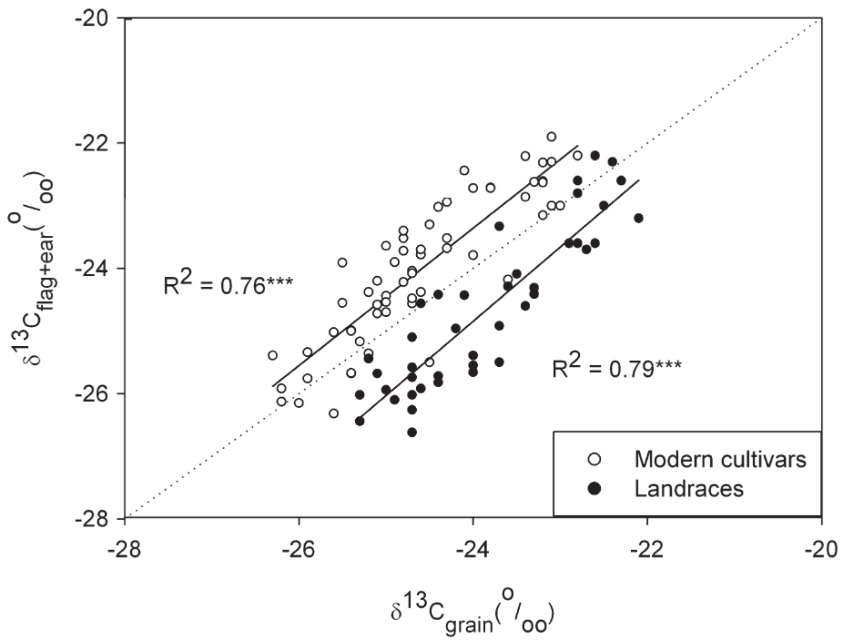


Sanchez et al 2014

The ear contribution was calculated as follows:

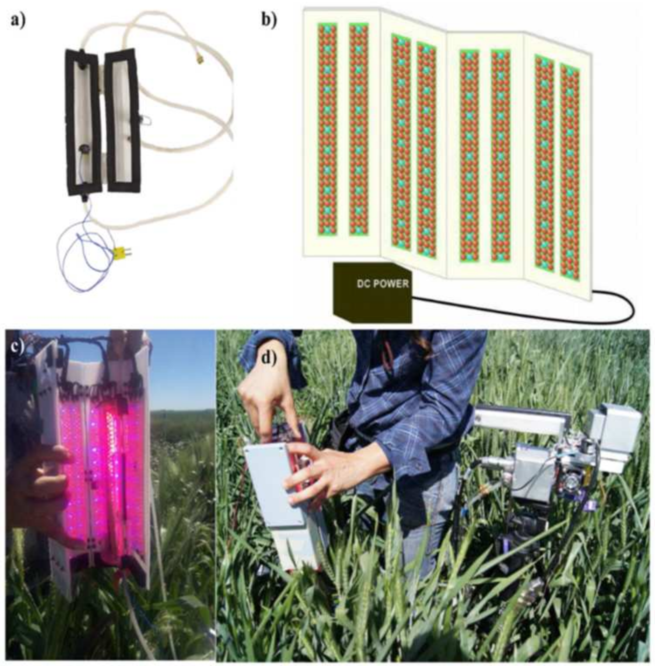
$$\delta^{13}C_{grain} = a \times \delta^{13}C_{ear} + (1 - a) \times \delta^{13}C_{flag}$$

where "*a*" is the ear contribution to grain filling, $\delta^{13}C_{grain}$ the carbon isotopic composition of mature kernels, $\delta^{13}C_{ear}$ the carbon isotopic composition in the WSF of the ear, and $\delta^{13}C_{flag}$ the carbon isotopic composition in the WSF of the flag leaf blade.

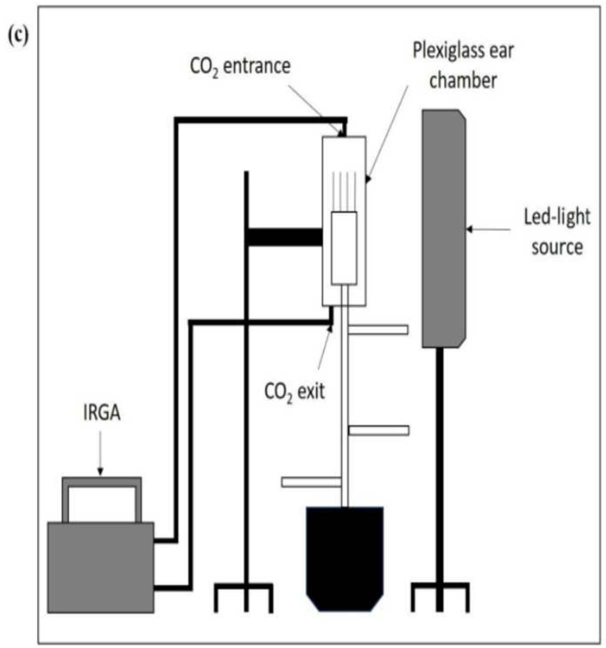


Methodological techniques for studying ear photosynthesis

- The direct gas exchange



Molero and Reynoldes 2020



Elazab et al 2021

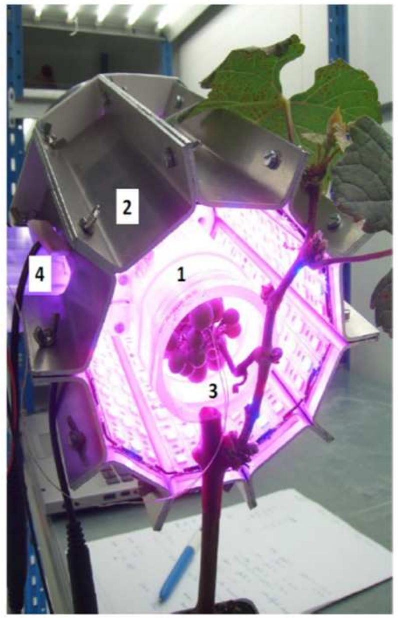


Fig. 1 Sample chamber (1) surrounded by the prismatic light source (2). A thermocouple (3) measures the temperature of the sample, which is a grape cluster. There is a hole through which tubing is passed, connecting the sample chamber and the infrared gas analyzer (IRGA) (4). For illustrative purposes, the back panel of the system is removed

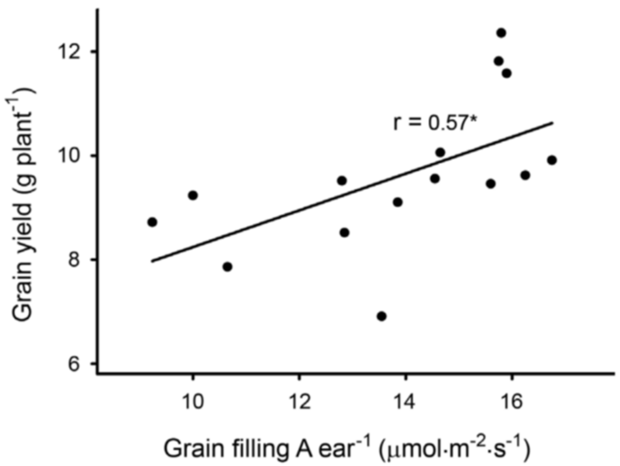
Fortineau and Bancal 2018

Spike and flag leaf photosynthetic rate, spike dark respiration rate, gross spike photosynthesis and morphological traits (awns and spike length) of the 45 lines evaluated from three different trials grown for two years in northeast Mexico under full irrigated conditions. G, genotype; Y, year. Heritability (H^2) presented is referred to broad sense heritability.

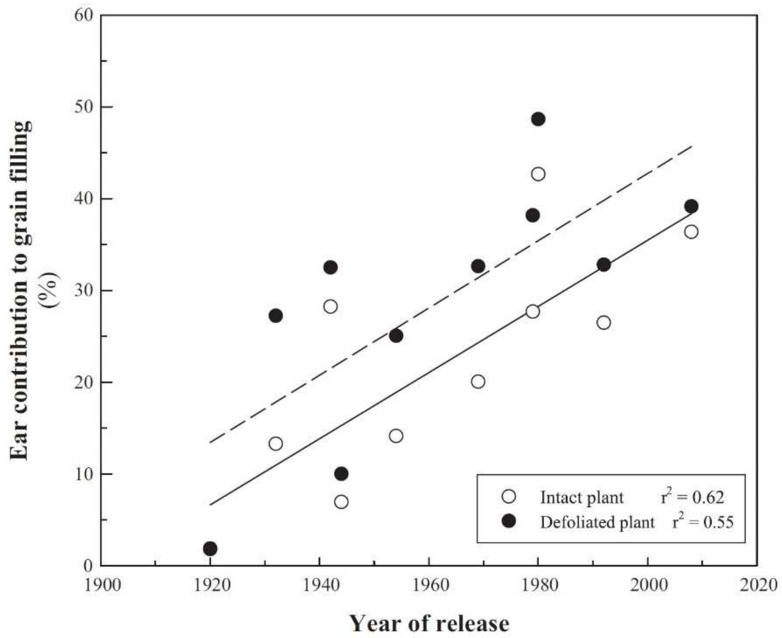
	Env	*n*		Spike Photosynthesis (μmol CO_2 m^{-2} s^{-1})	Spike Dark Respiration (μmol O_2 m^{-2} s^{-1})	Gross Spike Photosynthesis (μmol CO_2 m^{-2} s^{-1})	Flag Leaf Photosynthesis (μmol CO_2 m^{-2} s^{-1})	Spike Length (cm)	Awns Length (cm)
PADs POP‡									
2011 – 12	**YP**	12	Mean	15.7	15.2	32.2	28.2	–	
			H^2	0.409	0.868	0.390	0.500		
			P (G)	*ms* (0.054)	*	ns	ns		
CIMCOG I									
2011 – 12 & 2012 – 13	**YP**	15	Mean	11.6	14.7	26.4	25.6	12.1	5.1
			H^2	0.720	0.216	0.517	0.334	0.953	0.983
			P (G)	**	*	**	**	***	***
			P (Year)	ns	ns	*	*	**	ns
			P (G × Y)	ns	*	ns	*	**	**
CIMCOG II									
2013 – 14 & 2014 – 15	**YP**	18	Mean	13.5	14.1	27.6	25.9	12.4	6.7
			H^2	0.546	0.428	0.492	0.493	0.883	0.884
			P (G)	**	*ms* (0.061)	*	***	***	***
			P (Year)	ns	ns	ns	ns	ns	ns
			P (G × Y)	ns	ns	ns	**	*	ns

‡Only one year of data.
$^*P < 0.05$; $^{**}P < 0.01$, $^{***}P < 0.001$, ms $P < 0.1$; ns, not significant ($P > 0.05$).

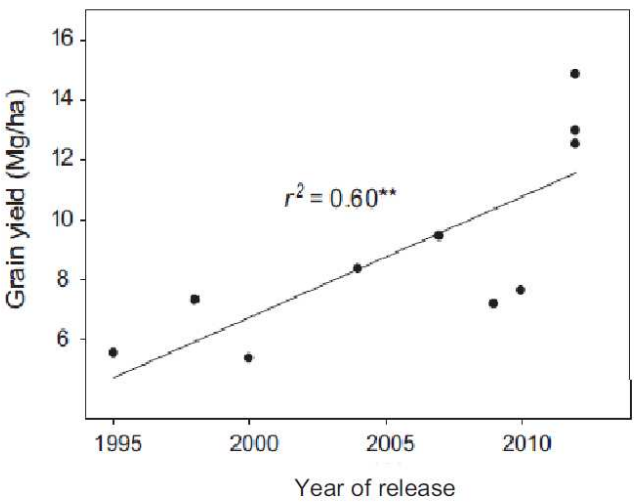
Molero and Reynolds 2020

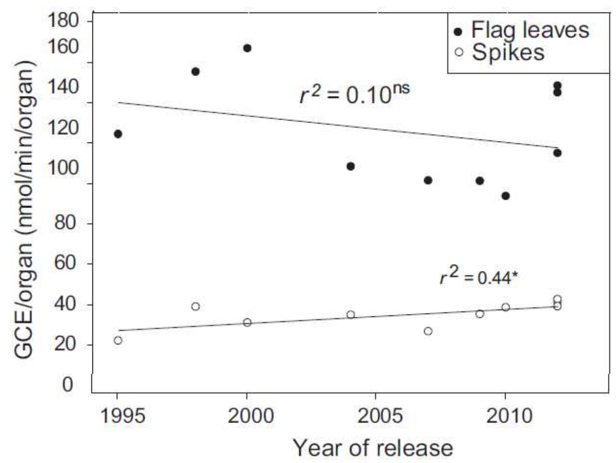


Zhou et al 2016

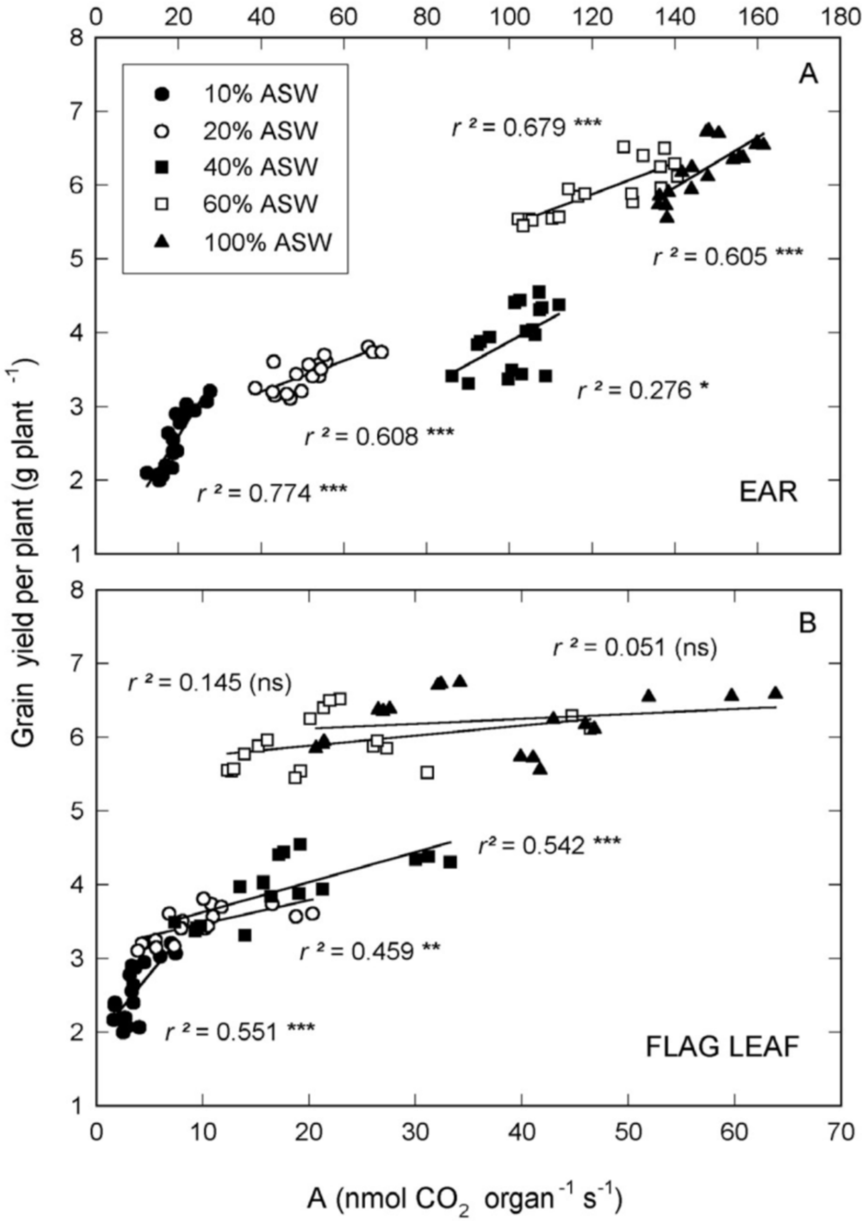


Maydup et al 2012

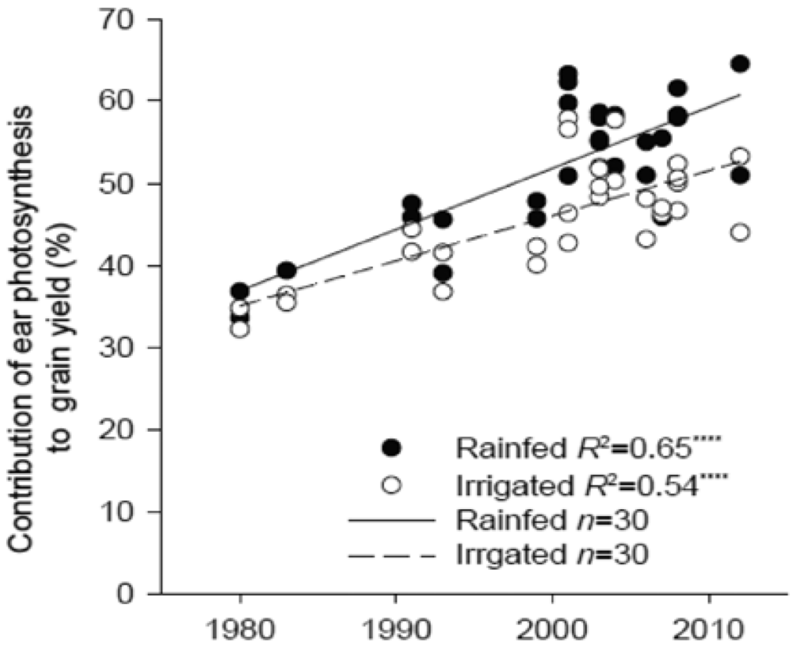




Zhou et al 2013



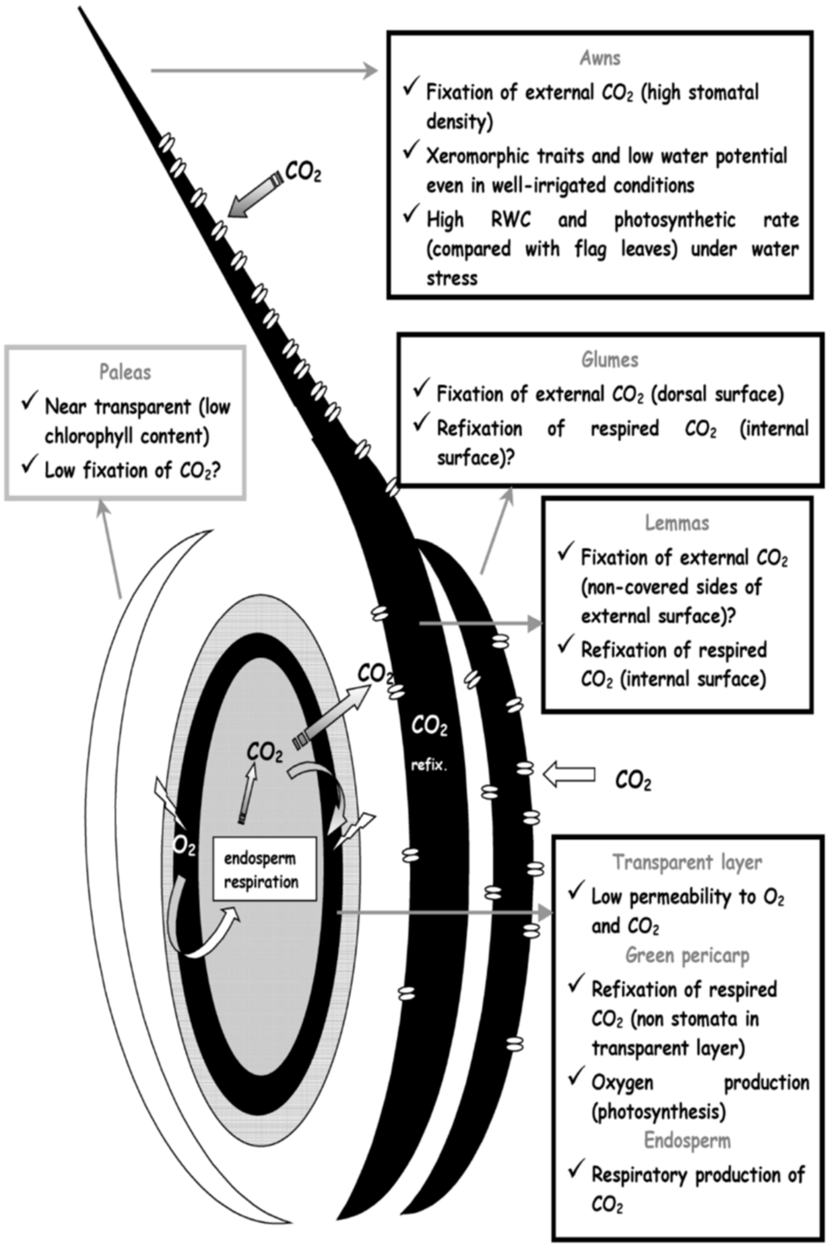
Abbad et al 2004



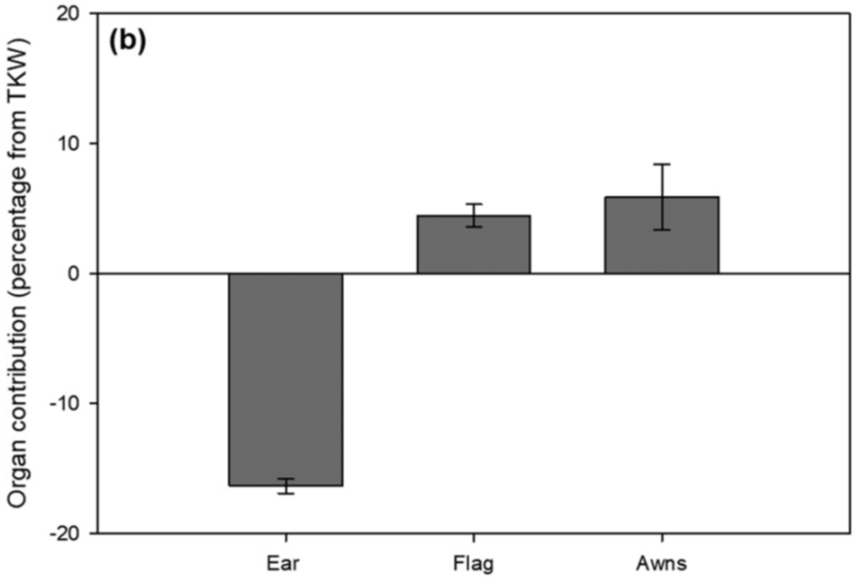
Wang et al. 2016

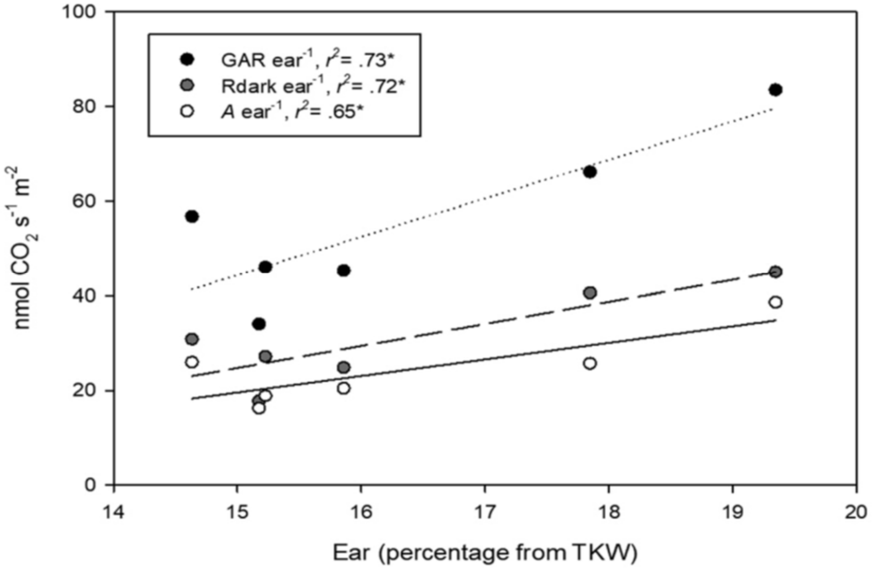
Why ear photosynthesis under stress conditions

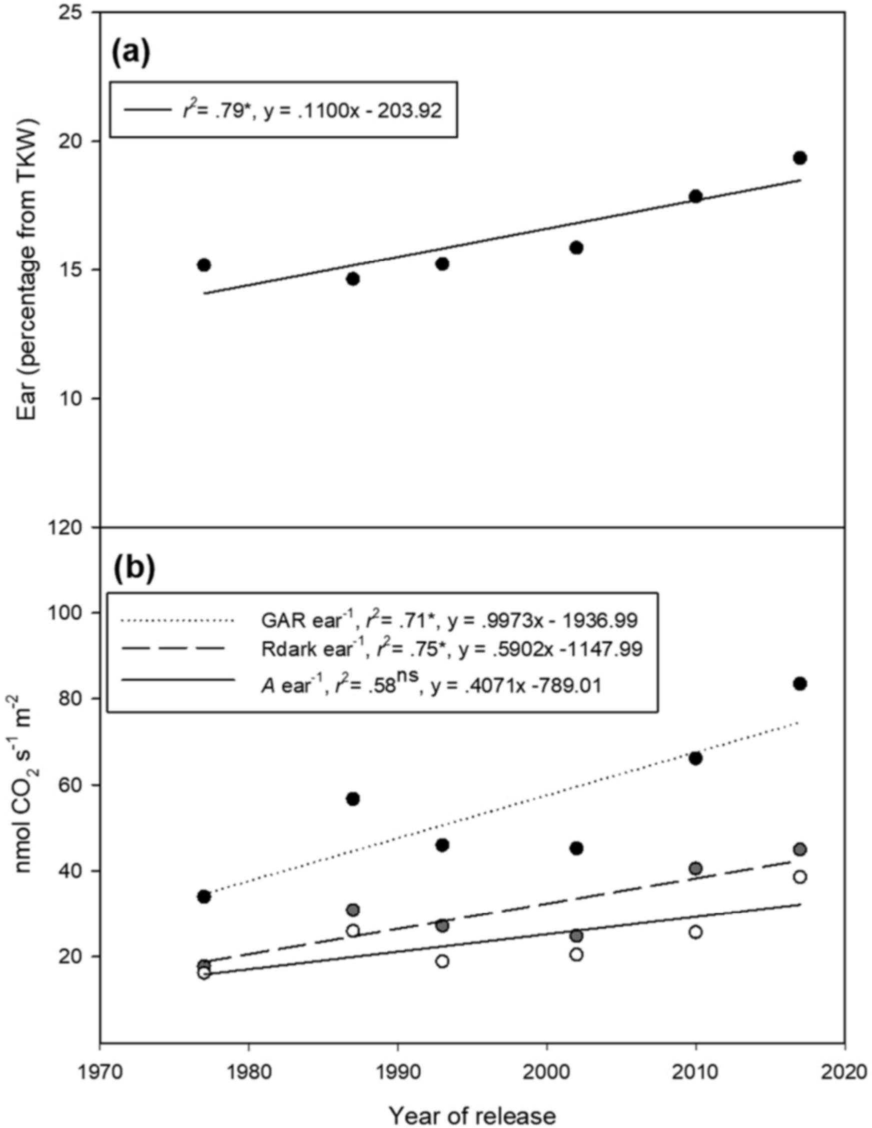
- Relative to the leaf, the ear has better CO_2 diffusive conductance during drought, suggesting efficient assimilation of CO_2 per unit of water transpired (Tambussi et al 2005)
- The ear has better osmotic adjustment; higher relative water content; and delayed senescence (Maydup et al. 2010).
- Further, the lemma and palea tightly enclose the developing grain and recycle respired 60-70% CO_2 , and thus, increasing transpiration efficiency (Araus et al 1993; Bort et al 1995).



Tambussi et al 2007







Elazab et al 2021

TABLE 5 Pearson correlation coefficients of the linear relationships between traits for six genotypes released between 1977 and 2017

Traits	AB	GY	HI	Ear m^{-2}	Kernel m^{-2}	Kernel ear^{-1}	TKW	PH	Ear length	FLA	DH
Ear (percentage from TKW)	.63[a]	.79	.64	.01	.74	.80	**.88***[b]	−.35	**.84***	−.03	−.40
Rdark ear^{-1}	.79	**.83***	.67	.40	**.84***	.75	.77	−.20	**.87***	−.18	−.54
A ear^{-1}	**.95****	**.80***	.48	.58	.78	.57	.74	−.39	**.87***	.19	−.76
GAR ear^{-1}	**.89***	**.84***	.60	.49	**.83***	.69	.78	−.29	**.89***	−.01	−.65
Rdark $flag^{-1}$	−.27	−.67	−.73	.31	−.68	**−.88***	−.60	−.38	−.64	.63	−.09
A $flag^{-1}$	.58	.60	.47	.43	.54	.36	.73	**−.87***	.63	.71	**−.89***
GAR $flag^{-1}$	.51	.46	.31	.47	.40	.18	.59	**−.91***	.49	**.80***	**−.87***

Note. Ear (percentage from thousand kernel weight, TKW), ear contribution; Rdark ear^{-1}, dark respiration rate per ear area; *A* ear^{-1}, photosynthesis rate per ear area; GAR ear^{-1}, gross assimilation rate per ear area; Rdark $flag^{-1}$, dark respiration rate per flag area; *A* $flag^{-1}$, photosynthesis rate per flag area; GAR $flag^{-1}$, gross assimilation rate per flag area; AB, aerial biomass; GY, grain yield; HI, harvest index; Ear m^{-2}, ears number per m^2; Kernel m^{-2}, kernels number per m^2; Kernel ear^{-1}, kernels number per ear; TKW, thousand kernel weight; PH, plant height; Ear length; FLA, flag leaf area; and DH, days to heading.

[a]The correlations were conducted using the genotype mean of the three replicates ($n = 6$).

[b]Bold figures represent significant correlations.

*$P \leq .05$

**$P \leq .01$.

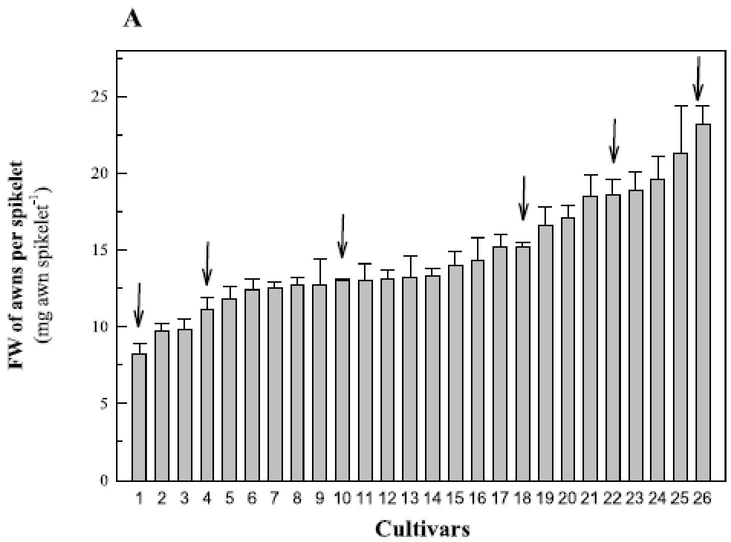
Elazab et al 2021

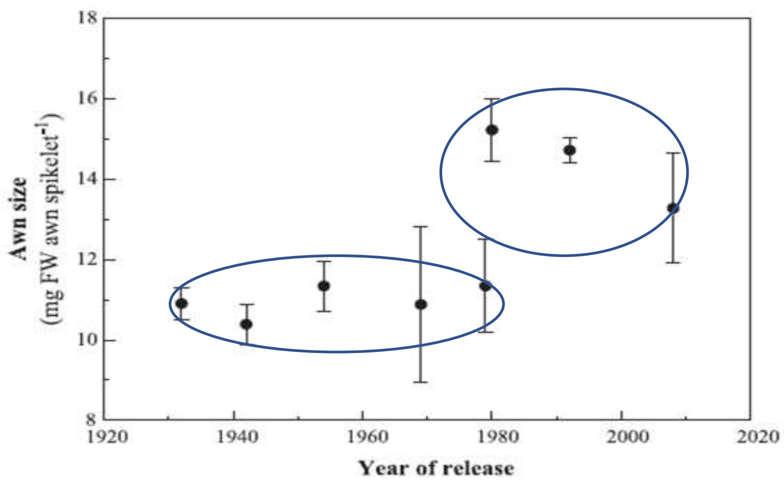
Awns importance for ear photosynthesis

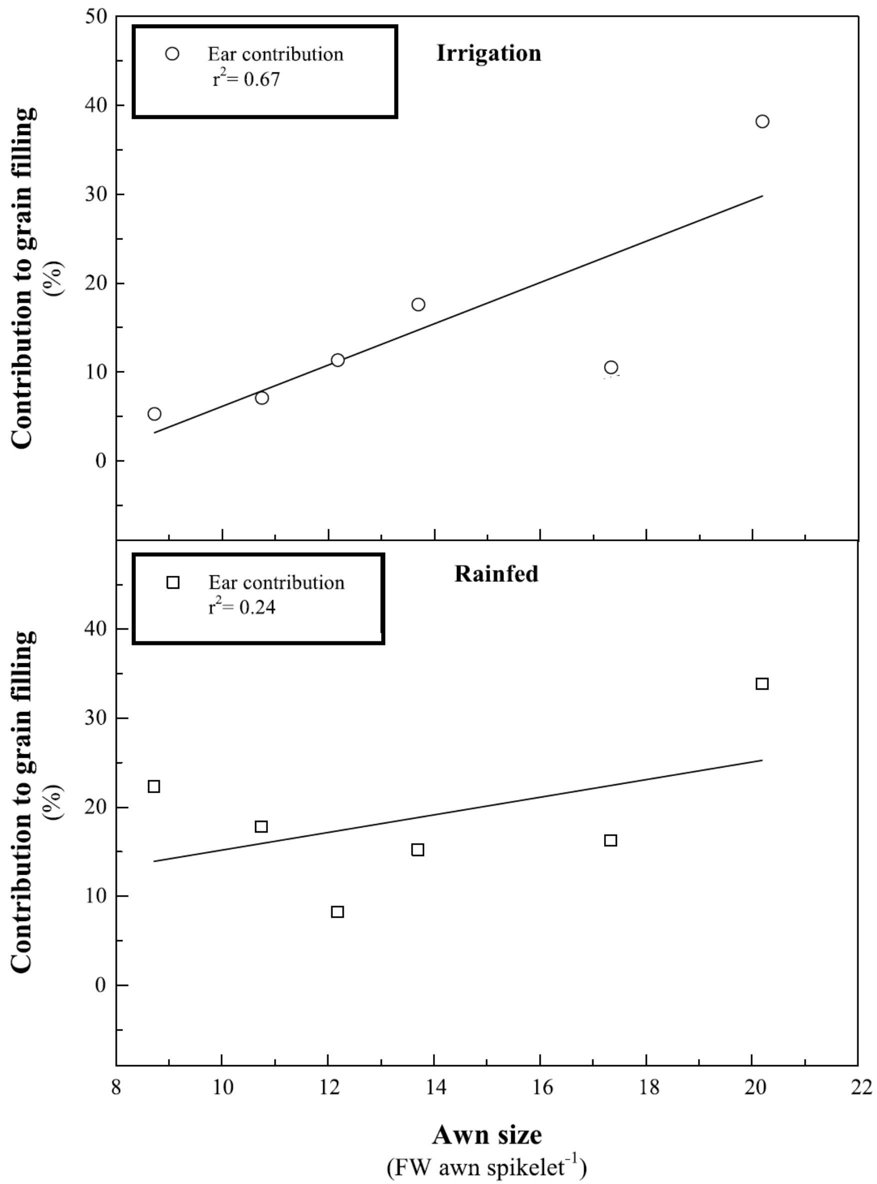
- They increase the photosynthetic area and total CO_2 assimilated in the ear. Awns of barley could contribute to 90% of ear photosynthesis under normal conditions, while in durum wheat it may contribute to 50% or more in some cases.

- Awns may affect ear temperature
  - A higher ear temperature is related with higher photorespiration and consequently can reduce net assimilation of CO_2 in the green parts of the ear.
  - Also, a negative relationship between canopy temperature (above 15 °C) during grain filling and grain weight is known for winter cereals such as barley and wheat (Savin, 2010).
  - Neutral, positive and negative effects were reported for awns on ear temperature.

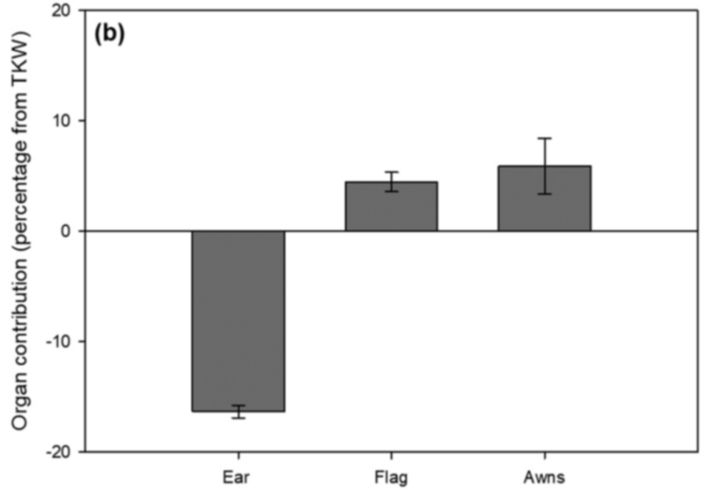
Barley







Adapted from Maydup et al (2012)



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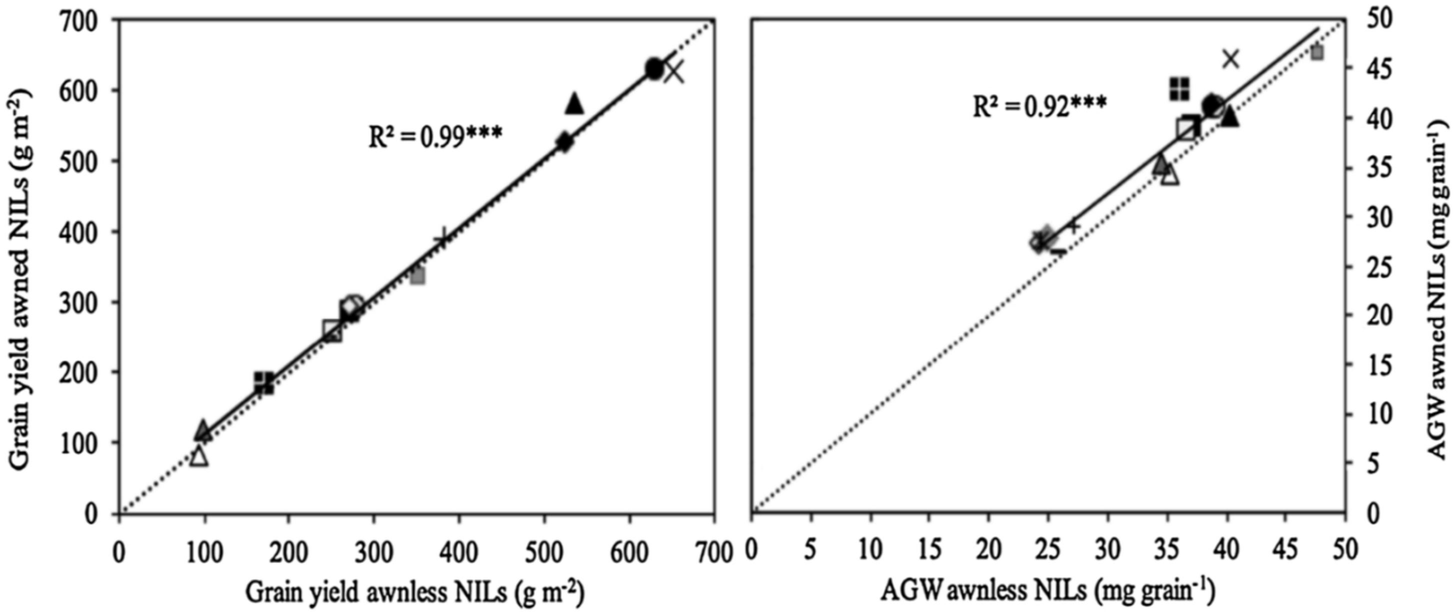

Sanchez et al 2020

Limitations of phenotyping for ear photosynthesis

Although it could form about 10 to 80% of the assimilate deposited in the grains, it has been less studied because:

- High genotype by environment interactions exist for the contribution of ear photosynthesis to grain (Maydup et al, 2010).
- The genotypic differences cannot be accounted only on the basis of the net photosynthesis of the ear because differences in the re-fixation rate of the respiratory CO_2 from the grains could also be involved (Gebbing and Schnyder, 2001)
- The time-consuming and the complex nature of measuring ear photosynthesis by gas-exchange methods especially when respiration needs to be measured. Moreover, there is no reported link between whole-ear photosynthesis and the relative contribution of this organ during grain filling (Sanchez-Bragado et al, 2014)
- Methodological limitations where most of methods to study the photosynthetic contribution of different plant parts to grain filling (i.e. source manipulation methods) include intrusive methods based on a differential (i.e. organ-specific) prevention of photosynthesis of some parts of the plant. Beside the intrusive nature of source manipulation methods, they could trigger compensatory effects that increase the contribution of unaffected photosynthetic organs or of the pre-anthesis reserves to grain filling (Maydup et al, 2012, 2014).