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Effects of Water Deficit and High Temperature During Grain Filling on Wheat Yield

Pengaruh Kekurangan Air dan Temperatur Tinggi Selama Periode Pengisian Biji pada Hasil Gandum

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Abstrak

Kenyataan menunjukkan bahwa kekurangan air di daerah-daerah semi-arid di dunia dan temperatur tinggi yang terjadi selama periode pengisian biji adalah merupakan faktor lingkungan yang utama dalam mempengaruhi penurunan hasil biji gandum *(Triticum aestivum L.)* Pengaruh kekurangan air pada komponen hasil telah banyak diteliti, namun penelitian tentang pengaruh kombinasi kekurangan air dan temperatur tinggi pada biji gandum masih sedikit dan belum banyak dipahami. Tujuan utama dari penelitian ini adalah untuk mengetahui pengaruh kombinasi antara kekurangan air dan temperatur tinggi selama periode pengisian biji pada hasil gandum cultivar Janz.
Dari hasil penelitian dapat disimpulkan bahwa kekurangan air dan kombinasi kekurangan air dengan temperatur tinggi menyebabkan perubahan pada pertumbuhan dan akumulasi protein biji yang selanjutnya akan berpengaruh pada penurunan hasil secara nyata. Penurunan laju dan durasi pengisian biji (setelah 30 hari setelah pembungaan pertama) menyebabkan makin cepatnya pemasakan biji.

Kata kunci : kekurangan air, temperatur tinggi, dan hasil gandum

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Introduction

Many studies have found that occurring early grain development or during linear phase of grain filling reduces final grain dry matter (Nicolas *et al.,* 1984 and 1985). Starch is the major component of cereal grain dry matter, and stress induced reduction in grain dry matter are accompanied by a reduced starch content. The response of duration of grain growth to water deficit is the primary determinant of responses of individual kernel mass to this stress. The duration of grain filling is generally reduced by post-anthesis drought in wheat, even by period of drought as short as 10 days (Brooks *et al.,* 1982; Nicolas *et al.,* 1984; Mogensen 1982).

Water deficit reduces the number of endosperm cells (Nicolas *et al.,* 1984) but not always (Brooks *et. al.,* 1982) and drought may also reduced the number of small starch granules. Cell size and number of small granules per cell were also reduced when water deficit took place during the late period of cell division. The degree of reduction in storage capacity and subsequent accumulation of dry matter depended on the intensity and timing of water deficit. Water deficit was more severe when high temperature was combined with drought, and the maximum number of endosperm nuclei was reduced by 50-60% under those conditions. The combined drought x high temperature treatment also caused the greatest reduction in the number of small and large granules per endosperm (Nicolas *et al.,* 1984).

Temperature is one of the major environmental factors affecting grain yield in crops. Several workers have concluded that temperature periods during the growing season are associated with low grain yield, mainly because of the increase in rate of development

which consequently the amount of radiation, water, nitrogen and other nutrients available to the crops (Mc Donald *et al.*,1983). It is estimated from the available field and phytotron data on the response of grain filling to high temperature and from what is known of the temperature conditions prevailing in the field following heading, that a yield penalty of 10 – 15% often results from above optimum temperatures during grain filling in both Australia and the U (Wardlaw and Wrigley 1994).

I the lower range, chronically high temperatures occur during grain filling with the mean varying from 18-25ºC and maximum day temperature up to 32ºC (Wardlaw and Wrigley 1994). Elevated temperatures commonly occur under two forms during the grain filling period (Jenner 1994; Stone and Nicolas 1994), (i) sustained periods of moderately high temperature (25 to 30-32ºC) and (ii) short periods (3-5 days) of very high temperature (ca. > 35ºC).

Material and Methods

Plant culture

Wheat was sown singly into 15 cm diameter pots containing 0,82 g of commercial potting mix (predominantly 5 mm pine bark, but containing river sand and peat moss) to which the following nutrients were added per pot: 1,7 g superphosphate (9,1%); 0,85 g urea (46% N); 5,1 g osmocote; 1,7 g micronutrient mix. Plants were grown in a naturally-lit glasshouse maintained at 21/16ºC, day/night temperature regime. The experimental design was completely randomised with five replications. Plants were watered every two days until imposition of drought treatments. At heading, small tillers were removed to leave 5 large and uniform tillers per pot. Small tillers produced after heading were removed every 3 days. Ears were individually labeled with the date on which anthesis first exerted (anthesis), and timing of all subsequent operation was related to anthesis.

Treatment

Drought treatment was imposed during mid (D1) and late (D2) grain filling by with-holding water for 10 days. Treatment started at 20 days after anthesis (DAA) (D1) and 28 DAA D2). Alkathene beads were spread over the soil surface to minimize soil evaporation. Drought treatment was stopped after 10 days when the flag leaf water potential reached –3,00 Mpa ± 0,24 (n=155).

A combined drought by high temperature treatment was also imposed during late grain filling (D2T), starting on 28 DAA, similarly to D2 treatment. Plants assigned to this treatment were transferred to a controlled-environment room, which was held at 32ºC during the day (12 h) and 20ºC at night (12 h), and relative humidity in the room ranged from 70 to 80%. The average photon irradiance (400-700nm) at plant height was 420 µmol m^{-2} s^{-1}. The DT treatment was interrupted after 3 days when the flag leaf water potential reach –3,00 Mpa ± 0,26 (n=75).

Measurements

For each treatment, five replicates were harvested at 2-day intervals throughout grain filling, starting at 10 DAA in the control; 28 DAA in the late grain filling drought treatment (D2) and the combined late drought and high temperature treatment (D2T) and concluding 60 DAA (maturity Harvest). At each harvest, eight grains per plant were removed from the a and b florets of two central spikelets on each side of the main stem ear (Stone, 1996).

Following fresh mass determination, grains were immersed in liquid nitrogen, freeze-dried and their dry mass recorded. Grain moisture percentage was calculated as the difference between fresh and dry mass, as a proportion of fresh mass. For each sequential harvest, five plants per treatment were sampled, while at maturity there were 50 plants for each treatment.

Rate and duration of grain growth for water deficit and heat stressed plants were calculated by applying logistic fits to grain data for the period following drought and heat treatment (Loss *et al*., 1989). These rates of

growth are compared with the rates of growth in the control treatment over the same period.

Protein content was determined by the Micro-Keldahl method, its procedure employed for the determination of nitrogen involves two steps: 1) The conversion of organic nitrogen to ammonium by digesting with concentrated sulphuric acid and hydrogen peroxide, and 2) subsequent determination of ammonium by steam distillation and titration.

Statistical Analysis

Frequency distribution for each component was obtained using the average of the five replicates used in the experiment. Population statistics (mean and standard deviation) were calculated using the 'Statview' package (BrainPower Inc., Calabasas, CA, USA). Initial calculation of responses for each treatment and ANOVA on those responses was performed using 'Genstat' version 5 (Rothamsed Experimental Station, Herts., UK).

Discussion

The earlier D1 treatment (20-30 DAA) caused a greater redaction in mature kernel mass than the later (28-38 DAA) D2 treatment (13.0 vs 6.6%). Similar results have previously been found for water deficit (Campbell and Davidson 1979; Morgan 1971), moderately high temperature (Tashiro and Wardlaw 1990) and heat stress (Stone and Nicolas 1995). Not unexpectedly, reductions of mature kernel mass were smaller with a later exposure to stress because the later stress occurred, the greater the amount of dry matter already accumulated. Indeed in this experiment, 44% of mature kernel mass had been accumulated by 20 day and 72% by day 28. Tashiro and Wardlaw (1990) suggested that reductions in kernel mass should not be expressed relative to the mature kernel mass, but relative to the increase in dry matter occurring after the start of the stress treatment. Using this method of calculation, the water deficit treatments D1 and D2 caused exactly the same dry matter reduction (23.2%), suggesting similar sensitivity of grain growth to water deficit treatments of similar stress intensity in the 20-30 DAA and the 28-38 DAA periods.

The combined late water deficit x high temperature treatment (D2T) reduce mature kernel mass most (15.4%). When the data were expressed as in Tashiro and Wardlaw (1990), the reduction in dry matter after 28 DAA was 54.2%, i.e. more than double the reductions calculated for D1 and D2. The greater reduction in grain dry matter accumulation was at least partly due to greater intensity of water deficit, but high temperature would also have directly affected grain growth. It was not the intention of this experiment to separate the effects of water deficit and high temperature, but rather to determine the effects of the combined stress as they frequently occur together in the field. Clearly, the combined stresses severely reduced grain dry matter accumulation, as previously observed (Nicolas *et al.*, 1984).

The reduction of grain filling, as estimated from logistic curve fitting, was reduced by ca. 23 in D1 14% in D2 and 30% in D2T. There was a significant, positive correlation between mature individual kernel mass and duration of grain filling ($R2 = 0.995$, $P = 0.005$). The maximum rate of grain filling, during the linear phase of growth from 10 to 30 DAA was not affected by the stress treatments. However during the next 10 days (30-40 DAA), when rapid water loss begun under stress (36 DAA in D1, 40 DAA in D2 and D2T), dry matter accumulation was reduced by ca. 35% in D1, 20% in D2 and 45% in D2T. This result implies that the rate of grain growth declined more rapidly under stress than in the control during the early maturation phase. Consequently it is clear that both reduced rates (after 30 DAA) and shortened durations contributed to the reductions in mature kernel mass following water deficit alone, or combined the high temperature.

The acceleration of the maturation process was also evident in the grain water content data (Figs. 4 and 5). The start of rapid water loss occurred 6 days earlier in D1 and 2 days earlier in D2 or D2T than in the control. Similar results have previously been reported (Brooks *et al.*, 1982; Nicolas *et al.*, 1985; Randall and Moss 1990).

Although protein accumulation was accelerated by the stress treatments, the protein content at maturity was unaffected. As dry matter accumulation reduced, grain protein percentage increased, as often observed under water deficit on high temperature stress. The acceleration of protein accumulation during stress (D2) or following stress (D1 and D2T) was most probably caused by increased proteolysis in senescing leaves and transport of the soluble nitrogen compounds to the grains.

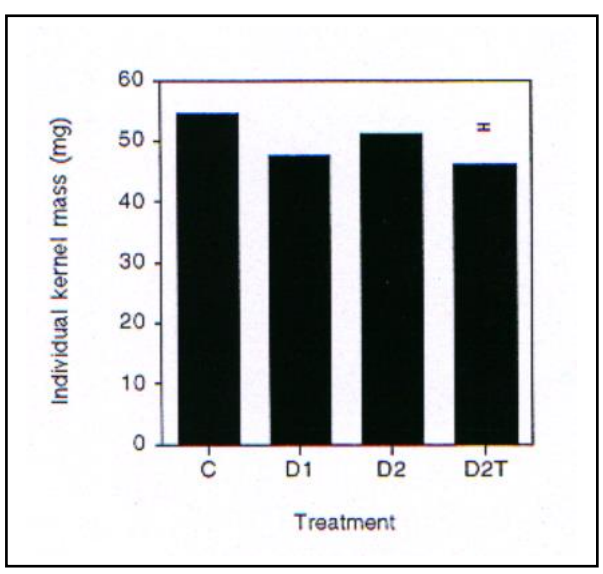

Figure. 1. The effect of water deficit and high temperature treatments on individual kernel mass at maturity of wheat cv. Janz. C: control treatment; D1: mid grain-filling drought treatment; D2: late grain-filling drought treatment; D2T: combined late drought x high temperature treatment. Bar is the l.s.d. (*P* = 0.05) for comparison of treatments.

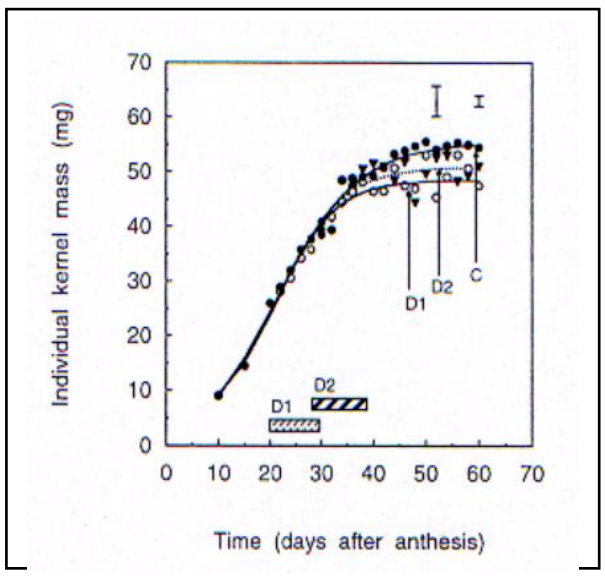

Figure. 2. Change of individual kernel mass with time in control (●), mid grain-filling drought (○) and late drought (▼) for wheat cv. Janz. Logistic fits are presented for the control (−) , mid grain-filling drought (----) and late drought (….). Arrows indicate physiological maturity. Bars are the l.s.d. (*P* = 0.05) for comparison of treatments.

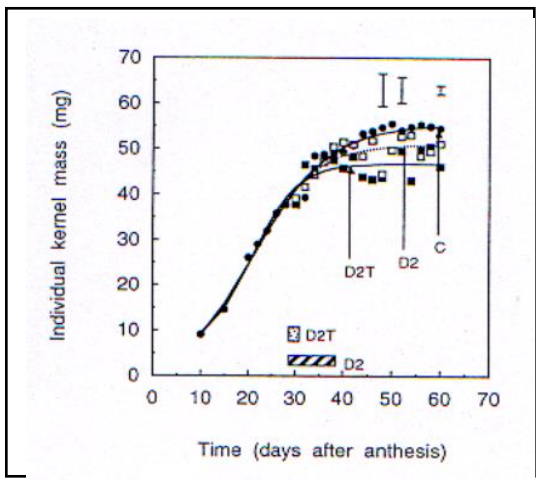

Figure. 3. Change of individual kernel mass with time in control (●), mid grain-filling drought (□) and late drought (■) for wheat cv. Janz. Logistic fits are presented for the control (−) , mid grain-filling drought (----) and late drought (….). Arrows indicate physiological maturity. Bars are the l.s.d. (*P* = 0.05) for comparison of treatments.

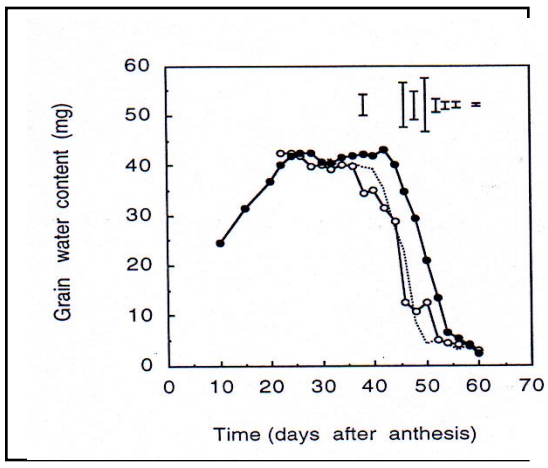

Figure. 4. Change of grain water content with time in control (●), mid grain-filling drought (○) and late drought (.). for wheat cv. Janz. Bars are the l.s.d. (*P* = 0.05) for comparison of treatments.

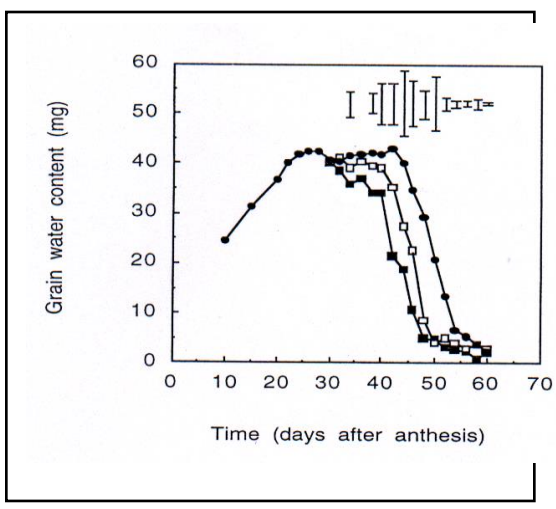

Figure. 5. Change of grain water content with time in control (●), mid grain-filling drought (□) and late drought (■). for wheat cv. Janz. Bars are the l.s.d. (*P* = 0.05) for comparison of treatments.

There as also significant protein accumulation (ca. 1 mg or 10% of total) and a significant increase in protein percentage after physiological maturity in the stress treatments (6, 7, and 8), although most of the grain water loss had occurred in D1 and D2, and rapid water loss was starting in D2T during that period of protein accumulation. These result suggest that, although the grains had nearly reached harvest ripeness, they were still importing some amino acids and synthesizing proteins.

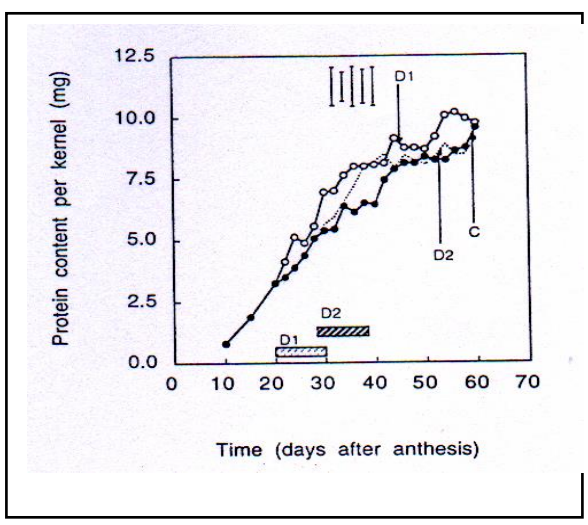

Figure. 6. Change in protein content per kernel with time in control (●), mid grain-filling drought (○) and late drought (….). for wheat cv. Janz. Bars are the l.s.d. (P = 0.05) for comparison of treatments.

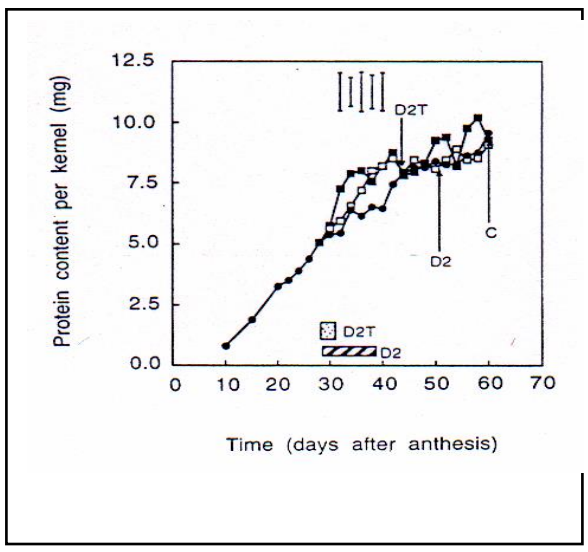

Figure. 7. Change in protein content per kernel with time in control (●), mid grain-filling drought (□) and late drought (■). for wheat cv. Janz. Bars are the l.s.d. (P = 0.05) for comparison of treatments.

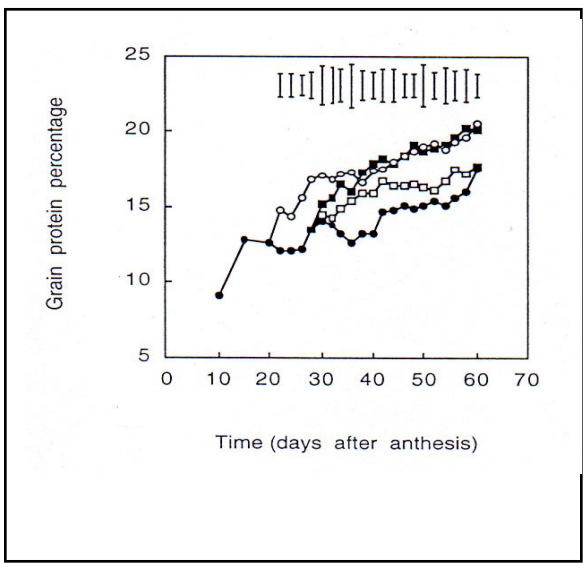

Figure. 8. Change of grain protein percentage with time in control (●), mid grain-filling drought (○) and late drought (□) and combined late drought x high temperature (■) for wheat cv. Janz. Bars are the l.s.d. (P = 0.05) for comparison of treatments.

Conclusions

Water deficit and combined water deficit x high temperature caused changes in grain growth and protein accumulation that were likely to affect grain. The reductions in rate (after 30 DAA) and duration of grain filling, corresponding to a more rapid grain maturation.

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