Supplementary calcium can help enhance photochemical activity in peanuts (*Arachis hypogaea*) leaves under low night temperature stress

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Exogenous calcium is able to maintain photosynthesis level under low night temperature (LNT) stress. Nevertheless, the mechanism for supplementary calcium to mitigate photosynthesis barriers under LNT has not been as clear as expected so far. This study mainly covered the response rules to Ca^{2+} and Ca^{2+} inhibitors for Photosystem II (PSII) photoinhibition, photochemical activity and allocation of absorbed light in leaves of peanut seedlings under low night temperature stress and during their recovery process. As the results indicated, low night temperature stress boosted excitation energy at PSII reaction centers of peanut leaves, and inhibited electron transfer, leading to imbalanced excitation energy distribution with lower photochemical efficiency between these two photosystems. The ratio of antenna heat dissipation increased, while the ratio assigned to photochemical reaction reduced in the process of light absorption, so photosynthetic efficiency declined. Foliar spray of exogenous calcium ameliorates the imbalanced excitation energy between Photosystem II(PSII) and Photosystem I (PSI), increasing electron transfer rate (ETR) and efficiency of light energy conversion at PSII reaction centers (Fv/Fm). More light energy is used for photosynthesis, thus promoting the growth of peanut seedlings. Supplementary calcium available helped to adjust PSII activity via increasing electron transfer rate, more excitation energy was transported to PSI, and the damage of PSII reaction center caused by excess excitation energy reduced. The increase of active reaction centers has enhanced the utilization efficiency of light energy.

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Abstract

Exogenous calcium is able to maintain photosynthesis level under low night temperature (LNT) stress. Nevertheless, the mechanism for supplementary calcium to mitigate photosynthesis barriers under LNT has not been as clear as expected so far. This study mainly covered the response rules to Ca^{2+} and Ca^{2+} inhibitors for Photosystem II (PSII) photoinhibition, photochemical activity and allocation of absorbed light in leaves of peanut seedlings under low night temperature stress and during their recovery process. As the results indicated, low night temperature stress boosted excitation energy at PSII reaction centers of peanut leaves, and inhibited electron transfer, leading to imbalanced excitation energy distribution with lower photochemical efficiency between these two photosystems. The ratio of antenna heat dissipation increased, while the ratio assigned to photochemical reaction reduced in the process of light absorption, so photosynthetic efficiency declined. Foliar spray of exogenous calcium ameliorates the imbalanced excitation energy between Photosystem II(PSII) and Photosystem I (PSI), increasing electron transfer rate (ETR) and efficiency of light energy conversion at PSII reaction centers (Fv/Fm). More light energy is used for photosynthesis, thus promoting the growth of peanut seedlings. Supplementary calcium available helped to adjust PSII activity via increasing electron transfer rate, more excitation energy was transported to PSI, and the damage of PSII reaction center caused by excess excitation energy reduced. The increase of active reaction centers has enhanced the utilization efficiency of light energy.

Introduction

Peanuts (*Arachis hypogaea*) are not only regarded as major oil crops and cash crops worldwide, but also as major food protein source and edible vegetable oil source, so they play a decisive part in edible oil safety in China (Fenget al., 2018; Mukesh et al., 2011; Kong et al., 2014). Low temperature is one of the environmental factors as restrictive to the geographic distribution and production for peanuts. Chilling damage prevails in peanut production for temperate regions in the whole world, particularly in the Chinese northern regions with high latitude, or in the southwestern regions with high altitude. Peanuts under low temperature stress often experience slow growth and seedling missing even upon recovery, so this shall severely impact peanut yield and quality formation (Bagnall, King&Farquhar, 1988; Liu et al., 2011; Prasad et al., 2003; Qin et al., 2011; Bhatnagarmathur et al.,2009; Kalisz et al., 2015). Low night temperature exerts its impacts to physiological metabolism for thermophilous plants, since photosynthesis, as the basis for plant growth and development, is one of the most sensitive processes to low night temperature stress (Damian&Donald, 2001; Liu, Qi & Li, 2012; Qin et al., 2011; Yu et al., 2002). Therefore, the necessity to improve photosynthetic capacity for peanuts after low night temperature stress is under urgent consideration in terms of both theoretical research and production practice.

Ca^{2+}, one of the essential elements for plants, serves not only as structure substance in cells, but also as the second messenger to adjust the response process of plants to environmental changes (Ding et al., 2018; Nash, Miyao&Murata, 1985; Patrick et al., 2018), allowing plants to enhance their cold resistance (Liu et al., 2013; Biswal et al., 2011). As some early studies have confirmed, calcium is most regulative to tomato photosynthate production and accumulation, and

plants with calcium applied enjoy better cold resistance and more yields (Zhang et al., 2014). Changes of these environmental factors lead to increased activity for free Ca^{2+} in cytoplasm, and then activity changes emerge for in vivo protein kinase as a result, hence inducing the related gene expression, or regulating related enzymes activity (Cheng et al., 2002). The early study by our research group has confirmed that foliar spray of exogenous calcium helped to improve peanut cold resistance remarkably. Nevertheless, the mechanism for calcium to mitigate low night temperature photosynthesis barriers has not been as clear as expected so far.

Chlorophyll fluorescent parameters are deemed as important indicators to assess if photosynthetic apparatus of plants is damaged, and then these parameters are applied to reflect the damage severity for plants under adverse stress. Both chlorophyll fluorescence in the plant leaves and photosystems in photosynthesis are highly related with those responses, such as light energy absorption, transfer, dissipation and allocation, so influence from these different factors on photosynthesis shall be represented via changes of chlorophyll fluorescent parameters (Piñol&Simón, 2009). In this experiment, further study was carried out with the help of changes of chlorophyll fluorescent parameters concerning the response rules to Ca^{2+} and Ca^{2+} inhibitors for PSII photoinhibition, photochemical activity and allocation of absorbed light in peanut seedling leaves.

Materials & methods

Plant material, experimental design and treatment

This experiment was performed from 2016 to 2017 at the plant nutrition research center of Chinese national technical system for peanut industry in Shenyang Agricultural University. The experimental cultivar was “Fenghua 1” (which was a famous cultivar in the main peanuts cultivating region). During this experiment, each sample was all under soil culture in a pot (a plastic one for culture with bottom hole R*H=20*26 cm), one plant in each pot with uniform watering and fertilizing to ensure consistency.

Then 15 pots of peanut seedlings in uniform style were selected and placed into the artificial climate chamber (CONVIRON, Canada), with daytime temperature 25℃, and night temperature 20℃. Those peanut seedlings, upon 3 days for adaption, were divided into such five groups as CK, LNT, LNT+Ca, LNT+EGTA and LNT+TFP. Ca^{2+} and its inhibitors with optimal concentration for regulation, which were screened in early experiments, were sprayed evenly onto these leaves by moisture sprayers two days before low night temperature stress (once respectively at 16:00 each day and twice in all). Treatments for each sample were presented as the following: CK (optimal night temperature 20℃/optimal daytime temperature 25℃+distilled water sprayed), LNT (low night temperature 10 ℃/optimal daytime temperature 25℃+distilled water sprayed), LNT+Ca (low night temperature 10 ℃/optimal daytime temperature 25℃+15mmol•$L^{-1}CaCl_2$), LNT+EGTA (low night temperature 10 ℃/optimal daytime

temperature 25℃+5mmol•L^{-1}EGTA) and LNT+TFP (low night temperature 10 ℃/optimal daytime temperature 25℃+0.5mmol•L^{-1}TFP). Group CK was defined as the normal temperature control one under treatment at night temperature 20℃, while the other groups were under treatment at low night temperature for 6 days. Later on, recovery treatment at optimal night temperature 20℃/optimal daytime temperature 25℃was conducted for 6 days, 12 days in all. Indicator determination and sampling were performed on treatment day 1, 3, 5, 7, 9 and 11 separately, and plant height was measured accordingly. Single plant measuring and sampling were performed and repeated for three times. Daily temperature treatment method: cooling from 19:00, up to night temperature at 21:00 (namely 20℃ and 10℃), then warming up from 9:00 the next morning, up to the defined temperature 25℃at 11:00 for each sample with their exposure to light (9:00-21:00), illumination intensity 600 μmol•m^{-2}•s^{-1}. The CO_2 concentration inside the culture room was 400 μmol•mol^{-1}, humidity 60% equally for day and night.

Determination of chlorophyll fluorescent parameters and fluorescence in-situ imaging

PAM chlorophyll fluorometer of Dual-PAM-100 (Heinz Walz GmbH, Germany) was used to determine chlorophyll fluorescent parameters.

The major parameters are listed as: Fv/Fm, efficiency of light energy conversion at PSII reaction centers, for which the more this value declines, the more damage PSII will suffer (Ort, Yocum&Heichel, 1996); qP, the photochemical quenching coefficient, which is reflective of photosynthetic activity magnitude (Cao, 1990), PSII reaction center openness magnitude (Ruban, Johnson&Duffy, 2012), together with PSII electron transport activity magnitude (Xu et al., 2008); NPQ, non-photochemical quenching coefficient, which is of a self-protective mechanism for photosynthetic system in a way (Ogweno et al., 2008); ΦPSII or Y(II), actual photochemical efficiency; ETR, electron transport rate, concerning the transport efficient for photosynthetic quantum (Bondarava, Beyer&Kriegerliszkay, 2005); 1-qP, PSII excitation pressure, representative of the ratio for PSII reaction centers in a closure state (Bilger& Schreiber, 1986); α, PSI excitation energy; β, PSII excitation energy; β/α-1, unbalanced coefficient for excitation energy between PSI and PSII; P, the energy for photochemical reaction which is supplied by PSII antenna pigment molecules from their absorbed light energy; D, heat dissipation; E, excess light energy from reaction centers.

IMAGING-PAM (Heinz Walz GmbH, Germany), the PAM chlorophyll fluorometer was employed in our experiment to depict the fluorescence imaging pictures of peanut seedling leaves under Ca^{2+} and Ca^{2+} inhibitors (EGTA, TFP). Then image color shades were referred to determine chlorophyll fluorescence magnitude, based on which to estimate impacts from Ca^{2+} ($CaCl_2$) and Ca^{2+} inhibitors (EGTA, TFP) on PSII photochemical activity of peanut leaves under low night temperature and during their recovery process.

Statistical analysis

Excel 2007 and SPSS software (Statistical Product and Service Solutions) were adopted in the statistical analysis to analyze experiment statistics and provide graphics.

Results

Effects of Ca^{2+} and Ca^{2+} inhibitors on peanut growth under low night temperature stress

Figure 1 and Fig. 2 showed the plant height contrast of peanut seedlings under different treatments after six days of LNT stress. As it demonstrated, all these four groups of peanut seedlings under LNT treatment grew more slowly than those under normal temperature (CK), while among these four groups of peanut seedlings under LNT stress, one group of plants sprayed with $CaCl_2$ grew significantly better than those with the other treatments, and the height was close to that of peanut seedlings under normal temperature. Whereas for plants sprayed with EGTA or TFP, they were under much severer LNT stress, particularly for peanut seedlings sprayed with TFP, for they grew flaccidly under the severest stress.

Effects of Ca^{2+} and Ca^{2+} inhibitors on PSII photoinhibition and photochemical activity for peanut leaves under low night temperature and during their recovery process

As Fig. 3 indicated, the maximum photochemical efficiency for peanut seedling leaves impacted by LNT, Fv/Fm declined markedly during LNT stress period. Though Fv/Fm of peanut seedling leaves sprayed with $CaCl_2$ was not up to that of CK, it was still higher than that under LNT treatment. Fv/Fm of peanut seedlings sprayed with EGTA or TFP were lower than that under LNT treatment, but Fv/Fm of peanut seedlings sprayed with TFP declined much more obviously. During normal night temperature recovery period, all these peanut seedlings under LNT treatment demonstrated a rise to different extent in terms of their photosynthetic activity. Those plants sprayed with calcium enjoyed the best recovery, basically up to CK level; plants under LNT treatment enjoyed an impressive rise in photosynthetic activity; plants sprayed with EGTA or TFP enjoyed a rise in photosynthetic activity, but not so conspicuous when compared with their initial values.

With Fv/Fm changes, ΦPSII, (the actual photochemical efficiency of PSII), and qP (the photochemical quenching coefficient), along with ETR (electron transport rate), all displayed the same variation trends (as shown in Fig. 4A, 4B and 4C). Nevertheless, NPQ, non-photochemical quenching coefficient, displayed a contrary variation trend (as shown in Fig.4D).

Effects of Ca^{2+} and Ca^{2+} inhibitors on allocation of absorbed light for peanut leaves under low night temperature and during their recovery process

As indicated in Fig.5A, 5B and 5C, both PSII excitation pressure and its allocation coefficient under LNT stress increased remarkably, while α, PSI excitation energy allocation coefficient, decreased distinctly (as shown in Fig.5C), so excitation energy balance between PSII and PSI was disturbed. During the whole process of LNT and normal night temperature recovery, α of peanut seedlings under LNT treatment was lower than that of CK, with β higher than that of CK.

As indicated in Fig.5D, such imbalanced allocation was perceived the most evidently at 5d during this experiment. 1-qP, β and β/α-1 all declined clearly at 11 d when compared with those at 5 d, but slightly higher than those during preliminary experiment period. Imbalance in excitation energy allocation was mitigated greatly for these plants when $CaCl_2$ was sprayed, but

severer imbalance in excitation energy allocation for plants emerged when Ca^{2+} inhibitors were sprayed.

As indicated in Fig.6, during the whole LNT treatment and normal night temperature recovery process, P-value assumed the trend of early decrease with later increase. From 1-5 d, with the extension of LNT stress duration, P-value under LNT treatment declined constantly, obviously lower than CK level at 5d in particular. However, for plants sprayed with $CaCl_2$ on their leaves, P-value at 1 d was on a visible rise, higher than that of CK, and then on a fall somewhat as the stress duration extended, but such a value was still higher than that of plants under LNT treatment. For peanut seedlings sprayed with EGTA or TFP, P-value dropped dramatically, especially for those sprayed with TFP. During recovery process at 7-11 d, photosynthetic activity for all the plants under LNT treatments improved equally, but P-value for plants sprayed with Ca^{2+} inhibitors was under slower recovery with a lower level. Absorbed light by PSII antenna pigments in leaves was mainly consumed during photochemical reaction transduction, and then the rest was consumed in the form of heat dissipation (D) and excess light energy (E) at reaction centers. As indicated in Fig.6, CK, LNT and LNT+Ca under LNT stress did not display any regular variations in a distinctive way. However, for plants under LNT+EGTA or LNT+TFP treatment, their heat dissipation portion increased remarkably—for 12.1% concerning plants sprayed with EGTA at 5d under LNT treatment, and for 10.6% concerning plants sprayed with TFP at 5d under LNT treatment. Accordingly, the excess light energy at reaction centers for these two groups of plants increased for 7.57% and 12.09% respectively.

Effects of Ca^{2+} and Ca^{2+} inhibitors on information acquisition concerning fluorescence in-situ imaging for peanut leaves under low night temperature stress and during their recovery process

Figure 7 presents the contrast pictures of fluorescence in-situ imaging for each parameter of plants at 5d under LNT stress and at 5d under normal temperature recovery. As illustrated, Fv/Fm changed the most distinctively, while photosynthetic capacity for peanut seedlings sprayed with $CaCl_2$ on their leaves under LNT stress was basically the same with that of CK. However, for plants sprayed with EGTA or TFP on their leaves, fluorescence imaging color displayed obvious changes, especially the group sprayed with TFP, whose color was light blue. Photosynthetic activity for this group steadily declined even during normal night temperature recovery, and the color turned green in the end. Y(NPQ), the quantum yield as regulatory to energy dissipation, is a critical indicator for photoprotection, while Y(NO), the quantum yield as non-regulatory to energy dissipation, is a critical indicator for photodamage. As known from the figure, plants under LNT treatment were impacted by low night temperature accordingly, and their Y(NPQ) value rose slightly, but Y(NPQ) value for plants under LNT+Ca, LNT+EGTA or LNT+TFP treatment rose significantly, and the last two treatment groups in particular, though Y(NO) showed no obvious changes at this moment. However, Y(NPQ) for leaves under LNT treatment rose somewhat upon normal night temperature recovery, and Y(NPQ) for leaves under LNT+Ca treatment declined remarkably. On the contrary, Y(NO) for leaves under TFP application rose remarkably. Low night temperature led to low quantum yields of peanut leaves,

while foliar spray of calcium was able to improve quantum yield, which was reduced by Ca^{2+} inhibitors in turn.

Discussion

Low night temperature stress is a common abiotic stress during crop growth and development process. Low temperature with its wider range of influence and obvious effects proves to be a fatal threat to crop high yield (Berry&Björkman, 1980). Currently, many reports home and abroad have indicated that low temperature is able to restrict chlorophyll formation by affecting photosynthetic apparatus activity of crop leaves, by affecting heat-sensitive ETR in PSII, PQ pool redox state, ETR in PSI (Liu et al., 2012) or by affecting plant physical characteristics, stomatal movement magnitude, for instance (Mathur, Agrawal&Jajoo, 2014). Then normal photosynthesis shall be inhibited further, which leads to restricted photosynthate accumulation, or even serious crop failure.

In this experiment, regulation by calcium ions to peanut seedling cold adaption was firstly studied, and then with focus on PSII, our study was carried out on how the calcium ions were able to mitigate photosynthetic barriers under LNT stress. As this study has confirmed, most measurement indicators represented some specific regularity under LNT stress and during normal night temperature recovery process. Simple analysis for peanut seedlings heights and Fv/Fm, the maximum photochemical efficiency, were conducted and showed that LNT stress forced peanut seedlings heights to be lower than that of CK, and their Fv/Fm value declined significantly. Thus, it was preliminarily concluded that LNT was able to affect photosynthetic capacity of peanut seedling leaves and restrict carbohydrate accumulation, so plant growth would be limited. For plants under foliar spray with $CaCl_2$, their photosynthetic efficiency recovered distinctively and this help to slow down plant height declination accordingly, while heights of those peanut seedlings under foliar spray with Ca^{2+} inhibitors declined further, and then their photosynthetic efficiency declined at different levels, too. It was much illustrative that Ca^{2+} played an important part in the trophic signal transduction to mitigate photosynthetic barriers for peanut plants under LNT. Ca^{2+} inhibitors, on the contrary, inhibited peanut seedlings growth and accelerated photosynthetic efficiency reduction further. When stress was removed, peanut seedling leaves under different treatments displayed recovery to various extent, so it meant that PSII was able to assume self-healing somewhat to enhance plant photosynthetic activity. Moreover, exogenous source of calcium as sprayed was able to help PSII improve its repair competence, allowing it to recover up to CK level. As for those under LNT did not recover up to CK level, it was just because PSII was damaged under LNT stress, and Ca^{2+} inhibitors intensified such damage further.

Under constant impacts from LNT stress, energy absorbed by PSII intended for photochemical reaction decreased gradually, which caused portion in the open state at PSII reaction centers to decrease accordingly, in spite of the same illumination intensity and the same number of electrons at electron donor side. Since the portion in the open state at PSII reaction centers fell down, PQ number under normal operation fell down as well. Electron accumulation at PQ aggravated and then restricted ETR in a further way. Moreover, the actual light energy conversion efficiency for PSII was also affected, as illustrated in Fig.4D, so with the purpose of

self-protection, PSII would release excess light energy by way of heat dissipation, namely non-photochemical quenching (NPQ). Calcium ions were able to help PSII apply more light energy to photochemical reaction, so plants under LNT stress, when sprayed with $CaCl_2$, displayed a mild decline apparently in terms of photosynthetic activities, actual quantum yield and ETR. For plants sprayed with EGTA, though their calcium ions extracellular were chelated, which inhibited absorption of calcium ions extracellular for these peanut seedlings, a specific number of calcium ions intracellular still remained there. Yet, for plants sprayed with TFP, their calcium ions united with calmodulin and were out of activity, so signal transduction function for the whole calcium signal system was blocked. As a result, for peanut seedlings sprayed with TFP, their PSII reaction center activity became weaker than that of peanut seedlings sprayed with EGTA. As indicated in Fig.4, during the whole LNT and recovery period, photosynthetic activity of plants under LNT treatment assumed the trend of early decrease with later increase, so it meant that PSII reaction centers were able to assume self-healing somewhat. However, due to low temperature damage, photochemical activity for peanut seedlings was not up to CK level, even if recovery was available at normal night temperature. qP and NPQ for plants sprayed with $CaCl_2$ boosted visibly, an illustrative fact that calcium ions not only helped to enhance reaction center activity and improve plant photosynthetic capacity, but also helped to accelerate heat dissipation dynamics, so that plants could dissipate their excess light energy as heat in a faster and better way to mitigate photoinhibition impacts on themselves. For plants treated with EGTA or TFP, since there was a lack of calcium ions, though their photochemical activity assumed an uptrend under recovery at normal night temperature, such elevated values were still lower ultimately as compared with those initial ones. This suggested that recovery at normal night temperature was available to mitigate inhibition effects from Ca^{2+} inhibitors, but PSII reaction centers were damaged irreversibly under LNT at early days.

1-qP, an essential parameter to evaluate if excitation energy captured by photosystem is to keep the balance with the energy applied (Havaux, Strasser&Greppin, 1991). LNT stress forced 1-qP, β and β/α-1 to rise, α to fall down at the same time, and this meant that more light energy flew from PSI to PSII, so PSII excitation pressure built up with more Q_A in reduction state, which shall hamper electron transport and reduce photosynthetic rate, inflicting damage to PSII accordingly. Excitation energy distribution among photochemical reaction (P), non-photochemical dissipation at reaction centers (E) and antenna heat dissipation (D) was affected at different levels. Under LNT stress, light energy absorbed by peanut seedling leaves for photochemical reaction (P) reduced remarkably, while portions used for antenna heat dissipation (D) rose distinctively, with qP down and NPQ up correspondingly. This indicated that light energy, normally intended for photochemical reaction, had to be dissipated in the form of thermal energy to tackle with the excess energy under LNT stress, since PSII was damaged and some of the reaction centers closed. However, from these two groups of peanut seedling leaves sprayed with Ca^{2+} inhibitors, we observed that not only D-value rose significantly, but E-value rose significantly as well. This indicated that Ca^{2+} inhibitors made PSII unable to converse all the excess energy, if only by way of heat dissipation. E-value increase shall boost PSII excitation pressure, causing triplet chlorophyll (^{3}Chl) to decrease and singlet chlorophyll (^{1}Chl) to increase.

Singlet chlorophyll shall transfer energy to O_2, then producing singlet oxygen ($^1O_2$) of strong oxidizability (Asada, 1999), and this shall do great damage to the photosynthetic membrane system of chloroplast (Diao et al., 2014). P-value rose rapidly for peanut seedling leaves with exogenous calcium application (E-value variations were not remarkably and D-value decreased), which all mitigated adverse impacts from LNT on PSII and enhanced leaves photosynthetic capacity.

Conclusions

Low night temperature stress decreased the photosynthetic activity of the peanut seedlings. The excitation energy between PSII and PSI was unbalanced, and then the electron transfer rate and the energy for photochemical reaction decreased significantly, but non-photochemical quenching coefficient increase significantly. Supplementary calcium can help enhance photochemical activity in peanuts leaves under low night temperature stress. Exogenous $CaCl_2$ protected the PSII from LNT stress via ameliorating excitation energy distribution imbalance and increasing the electron transfer rate of PSII, which improved the use of excitation energy and the accumulation of photosynthate. In contrast, plants that were sprayed calcium inhibitors (EGTA, ethylene glycol tetraacetic acid and TFP, trifluonerazine) are the opposite. This is an illustrative fact that as the receptor of Ca^{2+}, calmodulin (CAM) played an important role for Ca^{2+} in the thermal signal transduction to alleviate peanut photosynthesis barriers under low night temperature stress.

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Figure 1

Plant height of peanut seedlings contrast under Ca^{2+} and Ca^{2+} inhibitors after low night temperature stress.

Fig 1 - Plant height of peanut seedlings contrast under Ca^{2+} and Ca^{2+} inhibitors (EGTA and TFP) after six days of low night temperature stress.

**Note: Auto Gamma Correction was used for the image. This only affects the reviewing manuscript. See original source image if needed for review.*

Figure 2

Plant height of peanut seedlings contrast under Ca^{2+} and Ca^{2+} inhibitors after low night temperature stress.

Fig 2 - Plant height of peanut seedlings contrast under Ca^{2+} and Ca^{2+} inhibitors (EGTA and TFP) after six days of low night temperature stress.

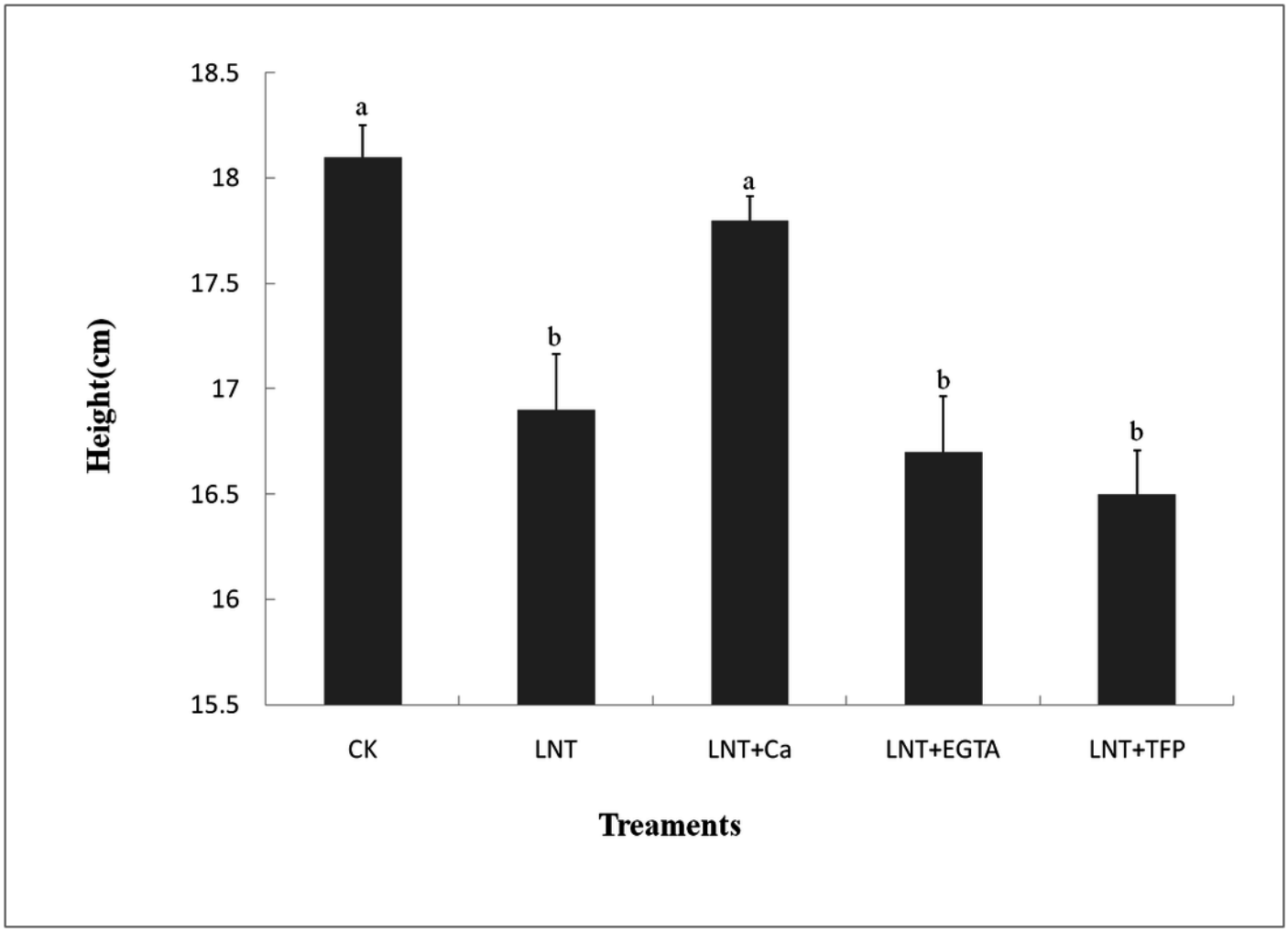

Figure 3

Effects of Ca^{2+} and Ca^{2+} inhibitors on Fv/Fm activity in leaves of peanut seedlings under low night temperature stress and during their recovery process.

Fig 3 - Effects of Ca^{2+} and Ca^{2+} inhibitors (EGTA and TFP) on Fv/Fm activity in leaves of peanut seedlings under low night temperature stress and during their recovery process.

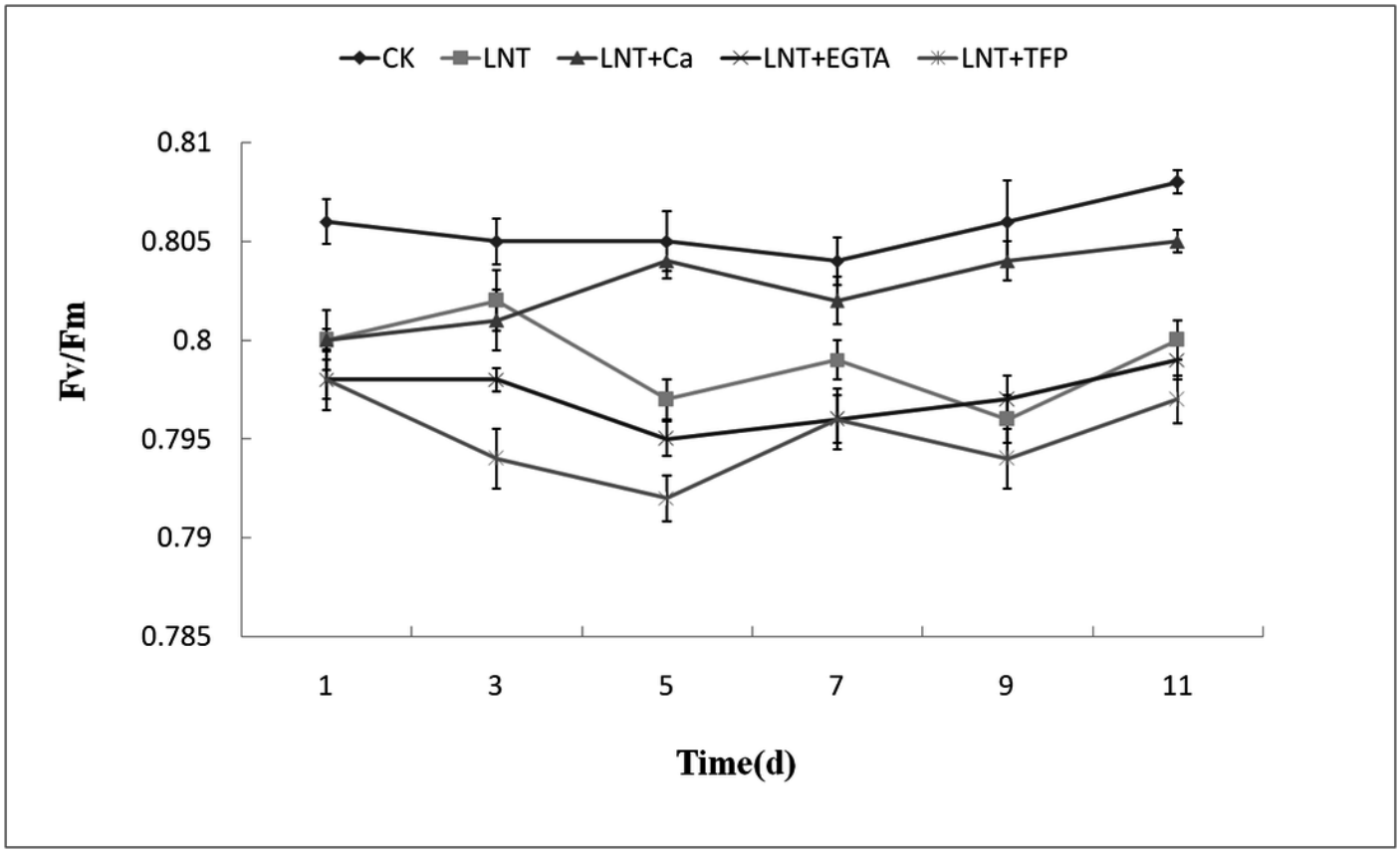

Figure 4

Effects of Ca^{2+} and Ca^{2+} inhibitors on ETR, φPSII, qP, NPQ activity in leaves of peanut seedlings under LNT stress and during their recovery process.

Fig 4 - Effects of Ca^{2+} and Ca^{2+} inhibitors (EGTA and TFP) on ETR, φPSII, qP, NPQ activity in leaves of peanut seedlings under low night temperature stress and during their recovery process.

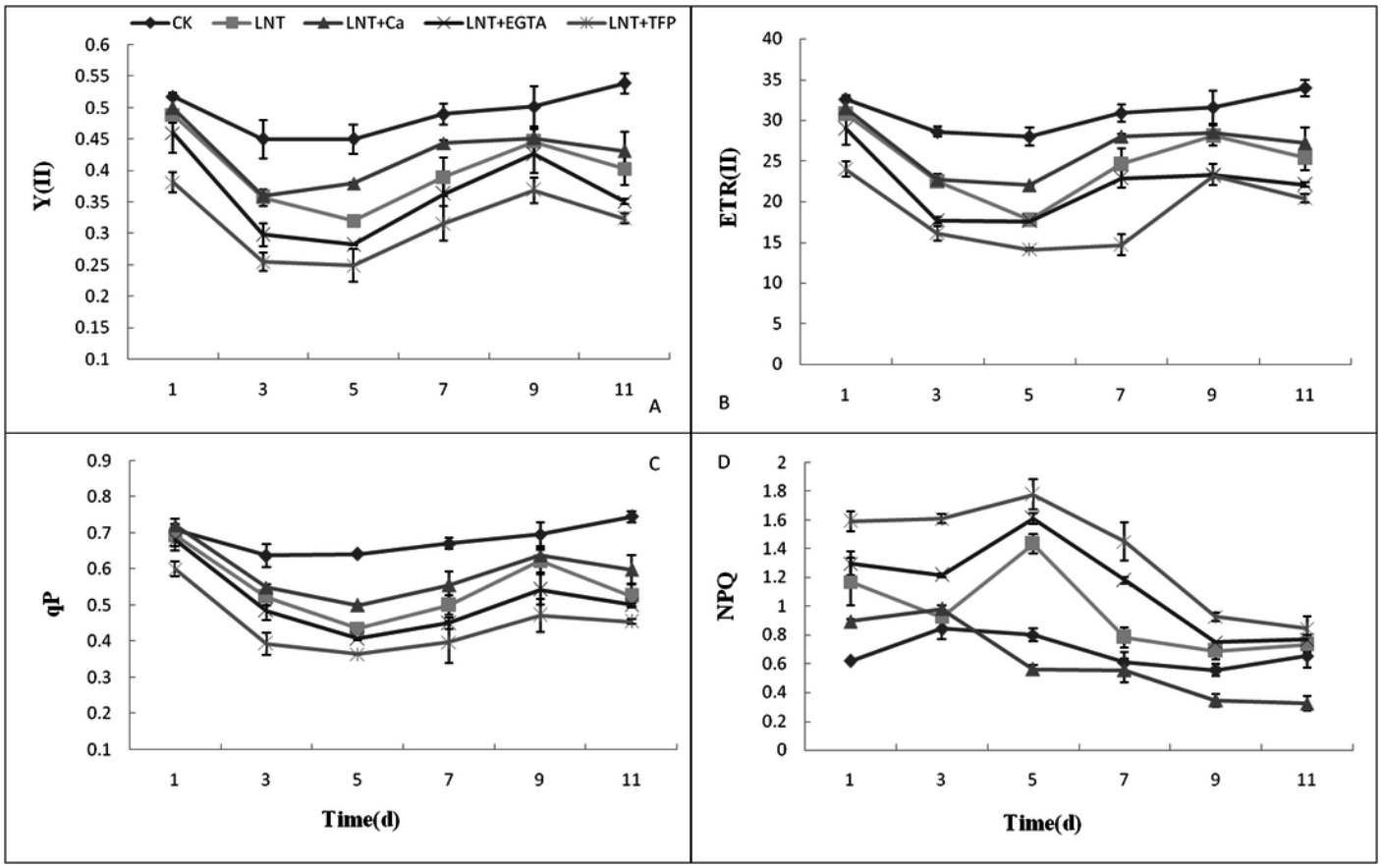

Figure 5

Effects of Ca^{2+} and Ca^{2+} inhibitors on1-qP, β, α and β/ α-1 in leaves of peanut seedlings under LNT stress and during their recovery process.

Fig 5 - Effects of Ca^{2+} and Ca^{2+} inhibitors (EGTA and TFP) on1-qP, β, α and β/ α-1 in leaves of peanut seedlings under low night temperature stress and during their recovery process.

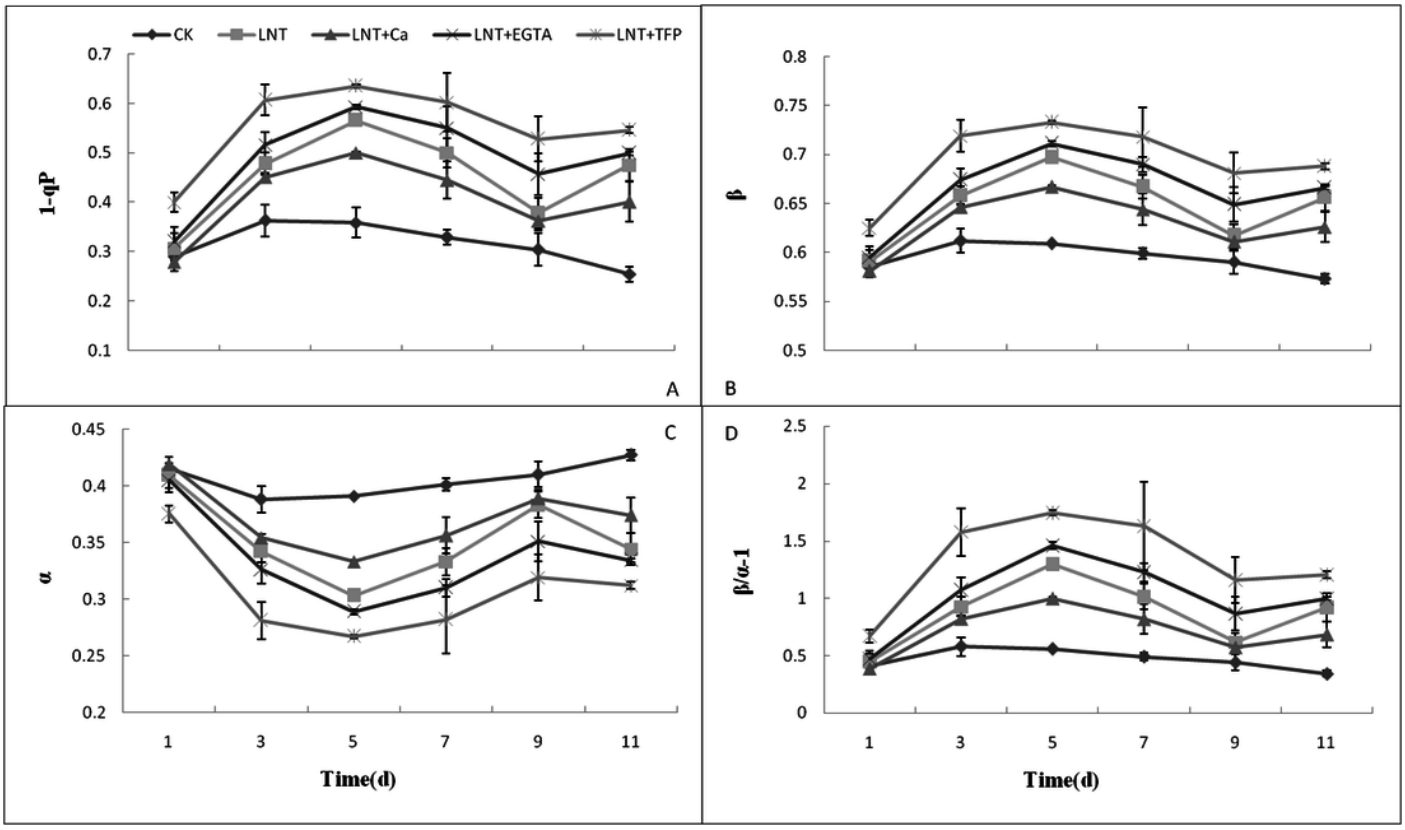

Figure 6

Effects of Ca^{2+} and Ca^{2+} inhibitors on the allocation of absorbed light of peanut seedlings under LNT stress and during their recovery process.

Fig 6 - Effects of Ca^{2+} and Ca^{2+} inhibitors (EGTA and TFP) on the allocation of absorbed light of peanut seedlings under low night temperature stress and during their recovery process.

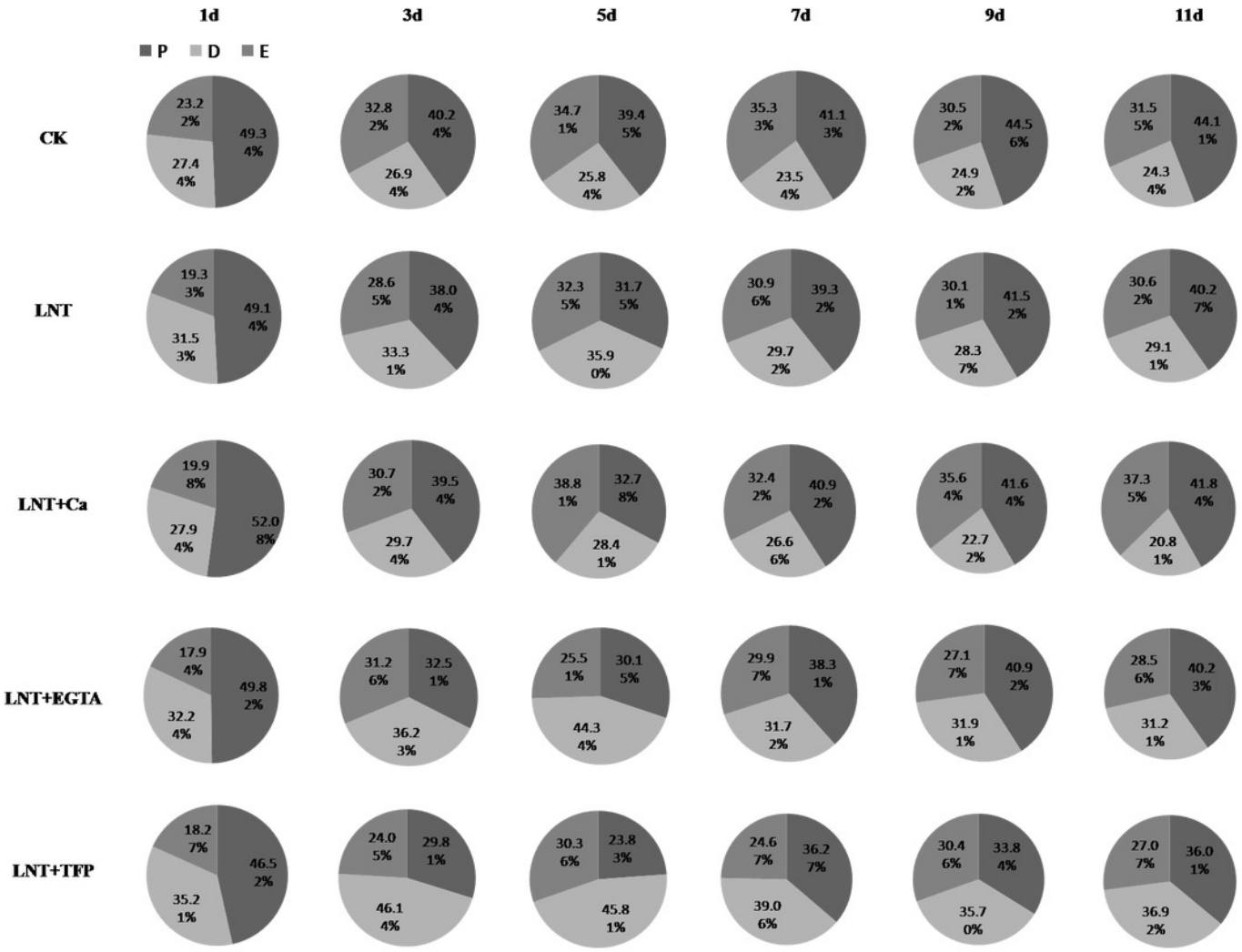

Figure 7

Effects of Ca^{2+} and Ca^{2+} inhibitors on fluorescence in-situ imaging pictures of Fv/Fm, Y(NPQ) and Y (NO) for peanut leaves under LNT stress and during their recovery process.

Fig 7 - Effects of Ca^{2+} and Ca^{2+} inhibitors (EGTA and TFP) on fluorescence in-situ imaging pictures of Fv/Fm, Y(NPQ) and Y (NO) for peanut leaves under low night temperature stress and during their recovery process.