A Dietary Tomato Supplement Prevents Prostate Cancer in TRAMP Mice

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Disclosure of Potential Conflicts of Interest

No potential conflicts of interest are disclosed.

Other notes:

Websites:


GraphPad: http://www.graphpad.com/quickcalcs/randomize1.cfm

Rodent Multi-Analyte Profile”:

http://www.rulesbasedmedicine.com/products-services/rodentMAP-antigen.asp

Abstract

The transgenic adenocarcinoma of the mouse prostate (TRAMP) is a model for progressive prostate cancer (PCa) that mirrors the stages of the human form. In this study, the effects of a diet enriched with processed whole tomatoes on survival, tumorigenesis and progression of PCa, and the antioxidant and inflammatory status of TRAMP mice were investigated. Tomato diet (TD) significantly increased overall survival ($P<0.01$), delayed progression from Prostatic Intraepithelial Neoplasia (PIN) to adenocarcinoma (ADK), and decreased the incidence of poorly differentiated carcinoma (PD). Biochemical data disclosed an increase in serum antioxidant activity, and a reduction of serum
inflammation/angiogenesis biomarkers of particular importance in prostate carcinogenesis.

Introduction

Prostate cancer (PCa) is the most common non-cutaneous malignant neoplasm in males in the Western countries. It is responsible for 30,000 deaths per year in the United States (1), and its incidence is increasing rapidly in function of the growing number of men over 50 worldwide. It is an ideal candidate for chemoprevention. Typically diagnosed in elderly men, even a slight delay in its development could substantially reduce the occurrence of clinically detectable forms. Dietary constituents are regarded as promising tools for PCa prevention (2, 3).

Epidemiological studies were the first to indicate that tomatoes, especially processed tomato products, are associated with a 30-40% reduction in PCa risk. A recent meta-analysis has revealed a reduction of the relative risk (RR) in the highest quartile of tomato intake of 0.89 and 0.81 for those consuming raw and cooked tomato products respectively (4). An inverse relationship between serum lycopene, the primary tomato carotenoid, and PCa has also been demonstrated (5), while intervention studies have shown that biomarkers related to prostate carcinogenesis may be altered by dietary administration of tomato products (6). A systematic review by the FDA, however, indicates that there is little robust evidence in favour of the supposed association between lycopene and reduction of PCa risk (7). Most experimental carcinogenesis studies of fruit and vegetable compounds used a “reductionist” approach to examine pure chemical components, especially lycopene, whether alone or in combinations. Lycopene is an O$_2$ quencher. It reduces oxidative DNA damage (8), and inhibits proliferation of various cancer cell lines (8 9). In animal experiments, lycopene supplementation down-
regulates numerous inflammatory marker genes and the genes of IGF-I and 5α-reductase in prostate tissue, with subsequent down-regulation of androgen target genes (10). However, in PCa patients tomato supplementation reduces serum prostate specific antigen (PSA) levels (11), whereas lycopene has no effect (12), and in rats tomato supplementation reduces carcinogenesis-induced mortality more efficiently than lycopene (13-15). Again, in the Dunning R3327-H prostate cancer model, the intake of whole foods, such as tomatoes and broccoli, slowed tumour growth more effectively than lycopene alone (16). Tomatoes contain other anticancer phytochemicals (see website in footnotes for reference), while constituents already present in small amounts or newly formed during processing also contribute to their final \textit{in vivo} efficacy (14).

The transgenic adenocarcinoma of the mouse prostate (TRAMP) is a model in which the progression of PCa mirrors the stages of the human form (17). Expression of the SV40 early genes driven by the prostate-specific promoter probasin leads to prostate cell transformation, and all TRAMP mice develop PCa spontaneously. This model, therefore, is regularly used to assess chemoprevention of PCa.

This paper compares the effects of a feed enriched with 10% whole tomato versus a tomato-free control feed in the TRAMP model. Its two primary outcomes were evaluation of: i) tumour incidence, and ii) overall survival rate. The secondary outcome was evaluation of serum biomarkers of particular significance in prostate carcinogenesis.

\textbf{Materials and Methods}

\textbf{Animals}. Male and female TRAMP mice, heterozygous for the PB-transgene, were maintained in a...
pure C57BL/6 background. Transgenic males were obtained by crossing C57BL/6 TRAMP females with C57BL/6 non-transgenic males, and bred in the Animal Care Facility (CeSI, G. d’Annunzio University Foundation, Chieti). Housing and care of the animals was in accordance with the guidelines established by the “European Convention for the protection of vertebrate animals used for experimental and other scientific purposes”.

**Feeds.** Two feeds were used: i) a commercial feed (Altromin MT diet; RIEPER, Vandoies, BZ, Italy) containing serum and milk proteins instead of soy and fish flours. This constituted the basic/control diet (CD); ii) a new feed in which the CD is supplemented with 10% tomato powder (hereinafter called the tomato diet or TD). This powder was spray-dried from heat-processed paste from whole cherry tomatoes, including seeds and skins. The paste was concentrated by means of a standard Hot Break procedure up to 40°Brix, and spray-dried without additives to obtain a powder with less than 5% humidity. The compositions of the powder and the two diets are reported in Table S1 and Table S2, respectively. The caloric value of the two feeds was similar with no significant difference in their macronutrient composition. They were stored at 4-6 °C in the dark.

**Study design.** Four-week-old male TRAMP mice were fed with CD for 1 week for adaptation. At 5 weeks of age, they were randomly distributed to the TD or the CD group in accordance with a free software routine (see website in footnotes for reference). All the animals were matched for weight and general physical condition. Two protocols were designed in function of the outcomes: in protocol 1, mice (18 in the CD and 18 in the TD group) were allowed to live until natural death or killed at the end of the study period. In protocol 2, five CD and five TD mice surviving the lethal development of PD
were killed at 12, 20, 25, 30 and 33 weeks. Ten mice were initially recruited for groups to be sacrificed at 12 and 20 weeks, 20 for the 25 week time point, and 30 for the last two time points. Blood (the first 5 samples obtained) and tissue samples were analysed as described below to evaluate and correlate, in each animal and at each time point, carotenoid and flavonoid concentration, total antioxidant capacity, marker protein content and pathological status.

**Blood and tissue collection and analyses.** Animals were anesthetized by CO₂ inhalation. Blood samples collected by cardiac puncture in heparinized tubes were centrifuged in the dark at 250g for 10 minutes to separate plasma, which was stored at –80 °C. After induction of death with a further CO₂ inhalation, prostate glands (dorsolateral, ventral, and anterior lobes) and seminal vesicles were removed, and micro-dissected whenever possible. When a tumour obscured the boundaries of the lobes it was taken as such.

**Histology.** Prostates and all major organs were examined for microscopic evidence of primary tumours/metastases. One-mm step sections were taken from formalin-fixed, paraffin-embedded tissue, and 5mm slices were stained with H&E. tumour volume was calculated from the formula $V = a^2 \times b/2$ (where $a$ and $b$ are the minimum and maximum in millimeters), and expressed as mean volume ± S.D. mm³ (irrespective of the finding). H&E and immunostained sections were examined with a Leica DMR microscope. Prostate lesions were classified as: a) low-grade intraepithelial neoplasia PIN, b) high-grade PIN, c) well-differentiated adenocarcinoma (ADK), d) moderately differentiated ADK, and, e) poorly differentiated (PD) tumours (18). The PD, androgen receptor (AR) negative, synaptophysin-expressing tumour is currently the lethal phenotype in the TRAMP model. It is a separate form, and not
a progression from the PIN and the well-differentiated ADK that arise from AR-mediated, SV40-Tag
transgene expression in secretory epithelial cells (18-20). The histopathological picture of TRAMP
mice also includes a non-metastasizing, fibro-epithelial (phyllodes) tumour in which proliferating
mesenchymal cells lined by cuboidal to columnar epithelium form papillary/polypoid lesions in the
seminal vesicles.

**Immunohistochemistry.** Immunohistochemistry was done on formalin-fixed, paraffin-embedded
tissues. The primary antibodies were anti-SV40 large T antigen (BD Pharmingen Franklin Lakes, NJ,
USA), anti-mouse AR, (Upstate, Lake Placid, NY, USA), and synaptophysin (Biogenex, San Ramon,
CA, USA). The biotinylated secondary antibodies were anti-rat IgG (1:200; DAKO, Glostrup,
Denmark) and goat anti-rabbit IgG (1:200; Santa Cruz Biotechnology, Santa Cruz, CA, USA).

**Serum protein analysis.** The concentrations of serum proteins (see the complete list in Table S3) were
measured at 12, 20, 25, 30 and 33 weeks of age (Rules-Based Medicine, Inc., Austin, TX) in a
quantitative multiplexed immunoassay (Rodent Multi-Analyte Profile, see website in footnotes), and
expressed as means ± S.E. pg/mL or ng/mL (n = 5). Since this technology requires only 70 ml of
serum, sufficient aliquots from the 20, 25, 30 and 33-week samples were available for the simultaneous
determination of carotenoid/flavonoid content and antioxidant capacity.

**Serum carotenoids, flavonoids and total antioxidant capacity.** Serum carotenoid and flavonoid
concentrations were determined at 20, 25, 30 and 33 weeks of age. Carotenoid determination,
conversion and HPLC analysis of sera, and serum flavonoid extraction and HPLC/MS/MS analysis of
the extracts were performed as previously described (21, 22). The ferric-reducing ability of plasma
(FRAP) was assayed according to the original description (23). Data were reported as mean concentrations ± S.E., expressed as nmol/L for carotenoids and flavonoids, and µmol TE/L for antioxidant capacity \( (n = 5) \).

**Statistics.** Overall survival was measured from the start of treatment to death, and censored at the last follow-up (48 weeks for survivors). Its distribution was estimated using the Kaplan-Meier method, and the difference between groups by means of the log rank test. The effects of treatment and time on serum biomarker levels were evaluated by 2-way ANOVA with repeated measures. *Post hoc* comparisons were then made with Bonferroni’s *t* test for pairwise multiple comparisons, with 5%, as the significance cut-off.

**Results**

**Protocol 1: a) Survival.** The Kaplan-Meier survival curves (Fig.1A) revealed a significant increase in the overall survival rate of the TD mice (67% vs 11%; *p*=0.0018). Histopathological examination disclosed PD tumours in 10 CD mice (56%) and 3 TD mice (17%). All these animals died spontaneously within the 31st (CD mice) or 33rd week of age (TD mice). All the other mice developed phyllode tumours of the seminal vesicles that were significantly smaller (two-tailed Mann Whitney U test, *P*<0.01) in the TD animals (volume: 147 ±141 mm\(^3\), *n* = 15, versus 428 ± 391 mm\(^3\), *n* = 8) (Fig. S1). This slow-growing tumour eventually gives rise to voluminous masses due to actively Tag-positive, fibroblast-like cells that obstruct seminal vesicles and urethers. Death is usually due to urinary blockage and consequent kidney failure.

**b) Metastatic progression** was confined to the mice with PD tumours. Six out of 18 CD mice...
developed liver, lung or periaortic lymph node metastases evident macroscopically in four animals and microscopically identifiable in two, whereas only one TD mouse displayed macroscopic liver and lung metastases.

c) Body weight. There were no significant differences in the mean body weights (Fig. S2).

Protocol 2: a) Prostate tumour development and progression. To evaluate the effect of the treatment on progression from non-neoplastic tissue to PIN and then to ADK, mice were studied at 12, 20, and 25 weeks of age (5 CD and 5 TD mice for each time point). The mean per cent areas of the dorsolateral prostate at these times were microscopically classified as non-neoplastic (normal), PIN (low- and high-grade PIN), and well- and moderately differentiated ADK (Fig. 1B). Their histology and immunohistochemistry are illustrated in Fig. 2. TD had a significant effect on tumour areas. At 12 weeks of age, the area with normal histology was greater in the TD mice (Fig. 1B, lower panel) than in the CD mice (Fig. 1B, upper panel) (96.1±3.1 % vs 58.0±5.6 %; P<0.01 two-tailed Mann-Whitney U test). In addition, TD mice displayed a significantly smaller area covered by PIN lesions and no ADK (Fig. 1B, lower panel and Fig 2 A, D). TD also had a striking effect on ADK: ADK involved 64.2±4.2% (CD mice) vs 3.0±2.3 % (TD mice) of the dorsolateral prostate (P<0.01) at 20 weeks, and 79.2±5.7% vs 10.0±3.9% at 25 weeks (Fig. 1B, and Fig. 2 B, C, E, F) (P<0.01).

At 25 weeks, neoplasia (i.e. areas with PIN and ADK) occupied 92.8% of the CD mouse and only 59.4% of the TD mouse prostate. In TD mice, too, 50% of the prostatic tissue was replaced by PIN and 9.4% by ADK, compared with 13.6% PIN and 79.2% adenocarcinoma in the CD mice. The histopathological picture of the CD mice also included PD tumours in 1/5 mice (4.2 mm3) and 3/5 mice...
(113 mm³, 376 mm³, and 402 mm³ at 20 and 25 weeks of age respectively). By contrast, a small PD tumour (4.2 mm³) was observed at 25 weeks in only one TD mouse (Fig. 2 G-I).

b) Serum biomarkers. The proteins quantitated with multiplexed immunoassay included several molecules widely recognized as significant prostate carcinogenesis biomarkers. The influence of TD on these serum biomarkers is illustrated in Fig. 3. TD mice displayed lower serum VEGF concentrations than CD mice ($P<0.0001$, ANOVA). A significant effect of time (weeks of age) ($P=0.048$), as well as a significant interaction “weeks x treatment” ($P=0.036$), were also observed. Post hoc comparisons with Bonferroni’s $t$ test for pairwise multiple comparisons showed that TD significantly decreased serum VEGF at 12 and 25 weeks ($P<0.05$ and $P<0.001$ respectively), and also modulated the concentrations of several angiogenic/inflammatory chemokines. TD mice sera had significantly lower concentrations of the angiogenic KC/GROα, MIP-2/GRO-b and MIP-1b (the angiogenic CCL3 chemokine) than CD mice. No differences were found for IL-8, MIP-1α, MIP-1γ, and MIP-3β serum concentrations. The peak level of KC/GROα, observed at 12 weeks in CD mice, was completely abolished by TD. Similarly, peak levels of MIP-1b and MIP-2 recorded at 20 weeks in CD mice were not present in TD mice. Although less impressive in terms of magnitude, a significantly lower concentration of the angiostatic IP-10 chemokine was observed in TD mice at 25 weeks (Fig. 3 S A).

TD markedly affected serum concentrations of many IL-6-type cytokines, namely IL-6 itself, oncostatin M (OSM) and IL-11 (Fig. 3), but not leukaemia inhibitory factor (LIF). In CD mice, IL-6 concentration peaked at 25 weeks (as in the case of VEGF), and IL-11 and OSM at 20 weeks, whereas in TD mice these cytokines were undetectable or barely detectable at 12 weeks and their concentration curves were flattened at significantly lower levels. TD was also significantly effective in lowering...
FGF-9 and IL-7 (Fig. 3) from the 12th to the 25th week. As shown in the supplementary material, TD lowered the serum concentrations of IL-10 (20-30 weeks), TNF-a (Fig. 3S A), SCF (20-25 weeks), MMP-9 (20 weeks) and MCP-1 (25 weeks) (Fig. 3S B). Effects on IL-1a and IL-1b were only observed at the latest times (from the 25th to the 33th week (Fig. 3S C).

TD had no significant effect on the concentrations of EGFR, Endothelin-1, FGF-basic, glutathione S transferase, ILs (from IL-2 to IL-5, IL-12, and IL-17), RANTES, TIMP-1 and the other proteins listed in Table S3.

c) Carotenoids, flavonoids and antioxidant activity in blood samples. All-trans lycopene was the only serum carotenoid. Its time-course concentration is only illustrated (Fig. 4) for TD mice because it was not detectable in CD mice. Flavonoids were only detected in low amounts. Rutin traces below the quantification threshold were present at 20 and 25 weeks, while a concentration of 4.10 nmol/L was found at 30 and 33 weeks. Traces of ishoramnetin 3-glucuronide were only present at 30 and 33 weeks. The antioxidant activity of these serum samples is illustrated in Fig. 4.

Post hoc comparison with Bonferroni’s t test for pairwise multiple comparison showed that TD significantly increased the antioxidant activity of blood (P<0.0001, P<0.05, P<0.05, and P<0.01 at 20, 25, 30, and 33 weeks respectively).

SV40 Tag antigen expression in the dorsolateral prostate. A major concern was that the preventive effect of TD might be due to direct suppression of the probasin promoter, resulting in reduced expression of the Tag transgene. As shown by immunohistochemistry (Fig. 2: inserts in A, B, D, E, G,
I), the Tag oncoprotein was expressed in the prostates of both CD and TD mice. Tag was also present in primary and metastatic PD. These observations suggested that the mechanism of tomato action against prostate cancer is not related to Tag expression, but to direct suppression of carcinogenesis.

Discussion

TRAMP mice on the TD survived longer than the CD controls, and displayed a lower incidence of poorly differentiated carcinoma. This is the first indication that whole-tomato supplementation improves TRAMP mouse survival.

This improvement (Fig 1A) was probably due to the ability of whole tomato to modulate both the tumour burden leading to urethral compression, urostasis and renal failure, and systemic metastasis. TD, in fact, reduced ADK and phyllode tumour growth, as well as the incidence of metastasis from the AR-negative PD tumour. As already mentioned, this is the main “lethal phenotype” in TRAMP mice due to both its rapid growth and consequent acute renal damage by compression, and as a source of distant metastases and systemic cachexia (18-20).

Our TD was specifically elaborated to have a high content and bioavailability of all bioactive tomato compounds. Prolonged heating of whole tomatoes, including their seeds and skins, maximised the concentration of flavonoids, and carotenoids (21) and promoted the formation of ketosamine (14).

The serum lycopene concentration in the 20-week-old TD mice (150 nM) was similar to that in rats on a 25% enriched TD (176 nM) (reviewed in 24). Its decrease to 90 nM at the 33rd week (Fig. 4) may have been due to disease-related factors, such as androgen status, oxidative stress and aging (15).
Reduced feed intake was suggested as a cause of diminished serum lycopene levels in Dunning prostate cancer rats on a diet supplemented with lycopene beadlets (25). This seems unlikely in our TRAMP model, because the body weights of the TD and CD mice were similar. As already mentioned, lower lycopene concentrations may have been due to the oxidative stress accompanying cancer progression, as recently demonstrated in the TRAMP model (26). Suppression of antioxidant enzymes (catalase, superoxide dismutase, glutathione peroxidase, heme-oxygenase-1 and phase II detoxifying enzymes) may provoke the \textit{in vivo} “consumption” of lycopene, and hence the formation of potentially bioactive oxidation and/or unselectively cleaved products, namely “lycopenoids” (27, 28). These compounds, together with the flavonoids (rutin and ishoramnetin 3-glucuronide) found in sera of TD fed mice may activate the Antioxidant Responsive Elements (ARE), and thus both ameliorate the oxidative status of TD mice and contribute to TD's anti-tumoral activity (28, 29). This suggestion is in line with the higher antioxidant capacity of TD mouse plasma.

Chronic inflammation/angiogenesis, too, is of importance in both mouse and human PCa development and progression (30, 31). This paper is the first report of a significant reduction of the serum levels of several pro-inflammatory/proangiogenic molecules of significance in prostate carcinogenesis following tomato treatment. According to a recent hypothesis for inflammation-induced prostate carcinogenesis, activated prostate epithelial stem cells acquire a survival advantage by expressing one or more of the same cytokines, such as IL-6. Establishment of one or more autocrine signalling loops expands these cells in the absence of inflammation as a potential first tumour development stage (32). The highly bioavailable cocktail of tomato phytochemicals may thus act pleiotropically at different levels. TD chemoprevention, in fact, was accompanied by a significant
systemic reduction of pro-inflammatory/pro-angiogenic factors. Several factors were reduced at 12 weeks, prior to tumour formation, and hence were probably involved in TD's chemoprevention mechanisms (33).

VEGF is highly correlated with angiogenesis and metastatization in both men and TRAMP mice (34-36). It was inhibited by TD, which delayed the angiogenetic switches needed for the development of PIN and PD tumours (35). In addition, TD selectively reduced the concentrations of other pro-angiogenic/pro-inflammatory chemokines such as KC/GRO-α, MIP-2/GRO-β and MIP-1b. but not those of MIB-1β, MIB-1γ and MIB-3b. Increased production of angiogenic chemokines by prostate tumour cell lines and in PCa patients has been documented. Furthermore, PCa xenograft growth is inhibited by antibody neutralization of KC/GRO-α (CXCL1) (37).

Prostate tumours from TRAMP mice also had higher mRNA for MIP-2 than noncancerous prostate tissues. This alteration was associated with increased activation of the NF-kB transcription factor, which regulates the expression of angiogenic CXC chemokines (38). MIP-1 induced vigorous migratory responses in DU-145 prostate cancer cells (39), and inhibits apoptosis (40).

The TD-dependent reduction of IL-7 concentrations may also result in an environment less favourable for cancer development: IL-7 induces VEGF independent proliferation of microvascular endothelial cells (41). TD markedly reduced serum concentrations of some IL-6-type cytokines, such as IL-6, OSM and IL-11. These cytokines and their receptors are expressed in the prostate, and regulate its growth in an autocrine and paracrine manner (see 42 for review). Since serum IL-6 and IL-11 concentrations increase in patients with metastatic and hormone-refractory PCa (43), measurement of IL-6 concentrations leads to more accurate prediction of disease progression and survival. In addition,
IL-6 plays an important role in the transition from an androgen-dependent to an androgen-independent state, promotes neuroendocrine differentiation, and contributes to cachexia in PCa patients (44, 45). Targeting IL-6 has thus been proposed as a potential collateral treatment for PCa.

Down-regulation of serum FGF-9 concentration by TD at 12 weeks of age may also contribute to the antineoplastic activity of tomatoes. Prolonged FGF signalling leads to prostate neoplastic transformation and tumour progression through autocrine and paracrine loops (46).

**Conclusions**

Daily consumption of a tomato-rich diet was highly effective in preventing PCa in TRAMP mice. In addition to its direct effects on tumour cells, tomato, a functional food containing a mixture of pleiotropic compounds (47), can be regarded as a biological response modifier whose establishment of an anti-inflammatory and anti-angiogenic environment prevents tumour onset and progression.
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Figure legends

Fig. 1A: Kaplan Meier survival curves for TD mice (dashed line) and CD mice (continuous line). 1B: Tumour progression in CD mice (upper panel) and TD mice (lower panel). Data are expressed as mean per cent ± S.E. (n = 5 per each age point) area of prostate with normal histology (no neoplastic prostate, open bars), with PIN, (dotted bars) and with ADK (closed bars).

* p < 0.01 between TD group and CD group (two-tailed Mann-Whitney U test).

Fig. 2: H&E (A-I) and Tag-SV-40 immunostaining (inserts) of prostate tissue from CD and TD mice: at 12 weeks of age. prostate of CD mice (A) shows large foci of PIN, which progress to diffuse ADK at 25 weeks (B); higher magnification of ADK (C) showing loss of intraluminal spaces, crowded gland-like tumoral cords, numerous atypical mitoses (arrows) and apoptoses (arrowheads); in TD treated mice at 12 weeks of age (D), there are few PIN foci in normal prostatic tissue; PIN is the most present lesion until 25 weeks (E), and ADK lesions are minimal (*); (F) higher magnification of PIN in tomato-treated mouse prostate: one or two layers of cells containing few mitoses (arrow) and apoptoses (arrowhead) line gland luminal spaces; (G) representative image of PD tumour from control and tomato treated groups showing diffuse sheets of cells with large necrotic areas (*), without remnants of glands; (H) higher magnification of PD tumour: chaotic arrangement of anaplastic tumour cells, aberrant mitoses (arrows) and apoptoses (arrowhead); (I) periaortic lymph node metastasis from PD prostatic carcinoma: tumour cells are clearly distinct from residual normal lymphoid tissue (circle and arrowhead). Tag-SV40 transgene expression is constant throughout TRAMP mouse PCa
progression from PIN to ADK (inserts in A, B, D, E); Tag-SV40 is also widely expressed in both primary and metastatic PD tumour (inserts in G, I) in both control and tomato-treated animals. CD= Control Diet. TD= Tomato Diet. PD= Poorly Differentiated tumour. (A, B, D, E, G, I: bar = 140µm; C, F, H: bar = 50 µm; inserts: bar= 90 µm).

**Fig. 3.** Dietary treatments influenced serum levels of several proteins related to prostate carcinogenesis. Values represent mean ± SD, n=5. P values (ANOVA) for each marker are reported. p values for *Post hoc* comparisons (Bonferroni’s *t* test for pairwise multiple comparisons) are also shown: * p<0.05, ** p<0.01, and *** p<0.001.

Closed square= Control Diet; Open Square= Tomato Diet.

**Fig. 4:** Plasma antioxidant capacity in CD and TD mice. Serum lycopene all-trans concentration is only shown for the TD group, since it is undetectable in CD mice. Data are expressed as mean ± S.E. (*n* = 5).
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