Potato consumption on oxidative stress, inflammatory damage and immune response in humans

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ABSTRACT

Background: Pigmented potatoes contain high concentrations of antioxidants including phenolic acids, anthocyanins and carotenoids, which are implicated in the inhibition or prevention of cellular oxidative damage and chronic disease susceptibility.
Objective: The purpose of this study was to assess the effects of pigmented potato consumption on oxidative stress biomarkers, inflammation and immune response in healthy adult males.
Design: Free living healthy male participants (18-40 yr; *n*=12/group) were given 150 g of cooked white- (WP), yellow- (YP) or purple-flesh potatoes (PP) once a day for 6 wk in a double-blinded study. Blood was collected at baseline and wk 6 to analyze total antioxidant capacity, DNA damage (8-OHdG), protein oxidation, lipid peroxidation, C-reactive protein (CRP), inflammatory cytokines, lymphoproliferation, NK cytotoxicity and phenotypes. Potatoes were analyzed for total antioxidant capacity, phenolic acids, anthocyanins and carotenoids.
Results: Participants fed YP and PP had lower ($P < 0.08$) plasma IL-6 compared to those fed WP. A concurrent decrease ($P < 0.08$) in CRP concentration was observed in the PP group. Lower concentrations of 8-OHdG were observed in subjects fed either YP ($P < 0.03$) or PP ($P < 0.08$) compared to those fed WP. Total Tc cells were lower while B cells were higher in PP compared to the WP group ($P < 0.05$). Compared to WP, YP had high concentrations of phenolic acids ($P < 0.002$) and carotenoids ($P < 0.001$), while purple potatoes had high concentrations of phenolic acids ($P < 0.002$) and anthocyanins ($P < 0.001$).
Conclusions: Pigmented potato consumption reduced inflammation and DNA damage, and modulates immune cell phenotype in healthy adult males.

INTRODUCTION

Diets rich in antioxidants are associated with a lower incidence of chronic diseases such as cardiovascular disease and cancer. Research has demonstrated that antioxidants such as phenolic acids, anthocyanins and carotenoids have been shown to reduce LDL oxidation, reduce DNA damage, inhibit cell proliferation and decrease CRP production, while improving immune cell function. The potato is the most commonly consumed vegetable in the US. In addition to high concentrations of vitamin C and iron, some potato cultivars are rich in phenolic acids, anthocyanins and carotenoids. Phenolic acids, such as chlorogenic acid, are found in white, yellow and purple potato cultivars. Purple-flesh cultivars have 186% more antioxidants compared to white-flesh potatoes, most notably due to the presence of anthocyanins, and have 3-4 fold more phenolic acids. Yellow-flesh cultivars are rich in lutein and zeaxanthin and can provide up to 10-fold more carotenoids than their white-flesh counterparts. We studied the potential health benefits of consuming pigmented potatoes on oxidative stress markers, inflammation and immune response in healthy humans.

MATERIALS AND METHODS

Healthy male participants between 18 and 40 y old were recruited from Washington State University and the surrounding communities. Exclusion criteria included chronic diseases, infection, and the use of tobacco, anti-inflammatory drugs and antioxidant supplements. Antioxidant supplements were avoided, and pigmented potatoes were not consumed outside of the study.

Free-living participants (n=12/group) were assigned in a randomized double blind, placebo-controlled experimental design to be fed the following: 1) white-fleshed Russet (WP), 2) yellow-fleshed (YP), or 3) purple-fleshed (PP) potatoes. Randomization was based on their baseline (wk 0) BMI. Participants consumed a total of 150 g of cooked potato daily for 6 wk. In order to maximize compliance, participants consumed their potatoes at our research site between 16:00 and 18:00 h. During the intervention period, participants kept a 3 d dietary log. Height and weight measurements were taken at baseline (wk 0) and the end of the intervention period (wk 6).

The white- (Ranger Russet), yellow- (PORO3PG6-3), and purple-flesh (PORO4PG82-1) potatoes were grown locally in Washington State in 2007 (USDA-ARS, Pomeroy, WA). In order to maximize retention of bioactive compounds, whole potatoes were boiled in a steam kettle for approximately 25 min, immediately cut into quarters, frozen in sealed small plastic bags, and stored at -35 °C until use. Appropriate amounts of potatoes were thawed and cooked every day. To minimize destruction of the bioactive compounds, potato recipes utilized quick-cook methods such as soups, mash and stir-fry. Butter, milk or vegetable oil was used in potato preparation, and condiments such as ketchup or hot sauce were made available to the participants. Fasting blood was collected from all participants at baseline (wk 0) and at the end of the intervention period (wk 6).

Blood assays. Blood collected at baseline and week 6 was analyzed for the following: plasma total antioxidant capacity (TAC), C-reactive protein (CRP), DNA damage biomarker (8-hydroxydeoxyguanosine, 8-OHdG), protein carbonyl and lipid peroxidation (TBARS). Immune response measured included the inflammatory cytokines (IL1-α, IL-1β, IL-2, IL-4, IL-6, IL-8, IL-10, IFN-ɣ anḍ TNF-α), lymphocyte phenotyping by two-color flow cytometry, mitogen-induced lymphocyte proliferation response, and natural killer (NK) cell cytotoxicity,

RESULTS

Demographics of the participants are presented in Table 1. All participants (n = 36) completed the study. No significant treatment differences were observed in age or BMI. Total caloric intake based on a 3 d dietary recall was lower ($P < 0.02$) in the PP treatment compared to YP or WP. There was no significant treatment x wk interaction for BMI. Participant compliance was excellent and no adverse side effects were reported.

Estimated amounts of antioxidants consumed daily by study participants are shown in Table 2. Total phenolics in YP and PP were about 1.5-fold greater than WP. The YP group consumed between 30 and 38-fold more carotenoids than WP or PP. The WP and YP groups consumed few anthocyanins while the PP consumed at least 24-fold more. Total antioxidants, assayed by TAA, were almost 2-fold higher in PP compared to YP, and YP was 3-fold higher than WP.

C-reactive protein. Plasma CRP concentrations in PP (1.3 ng/L) were lower ($P < 0.08$) than in WP (3.4 ng/L) at wk 6 (Figure 1). Concentrations also tended to be lower in YP (1.8 ng/L) than WP.

DNA damage. Plasma 8-OHdG concentrations in YP (27.3 ng/mL, $P < 0.03$) and PP (29.4 ng/mL, $P < 0.08$) were significantly lower than in WP (37.6 ng/mL) at wk 6 (Figure 2).

Total antioxidant capacity. There was no significant treatment difference in plasma TAC after 6 wk of potato consumption however, TAC in YP and PP treatments (2.2 mM) tended ($P > 0.05$) to be higher in WP (1.9 mM) (Table 3).

Protein carbonyl. Plasma protein carbonyl content showed no significant difference between treatments at wk 6. Plasma protein carbonyl averaged 6.1 nmol/mL across all treatments (Table 3).

Lipid peroxidation. Concentrations of plasma TBARS were not significantly different among treatments at wk 6 (Table 3).

Cytokine production. Plasma cytokine concentrations are shown in Table 4. Concentrations of plasma IL-6 in YP ($P < 0.08$) and PP ($P < 0.08$) treatments were lower compared to WP (Figure 3). In contrast, no significant differences were observed in plasma IL1-α, IL-1β, IL-2, IL-4, IL-6, IL-8, IL-10, IFN-γ and TNF-α concentrations among treatments.

Lymphocyte phenotypes. The distribution of different lymphocyte subpopulations are shown in Table 5. The B cell population at wk 6 was higher ($P < 0.03$) in PP (9.3%) than in WP (6.7%) (Figure 4). Among the different T cell subsets, subjects in YP generally had higher percentages of total T cells and Th cells than in WP. The Tc cell population in PP (25.0%) but not in YP (28.5%) was lower ($P < 0.05$) than in WP (28.5%) (Figure 4). The ratio of Th:Tc was similar among treatments, averaging 1.3. Subjects in PP tended to have the highest percentage of NK cells (26.3%). These results suggest that subjects in YP had numerically lower B and NK cell subpopulations and higher T cell populations than WP. Those in PP tended to have higher B and NK cell populations but lower T cell populations.

Lymphoblastogenesis. Lymphoproliferation induced by B and T cell mitogens. No significant treatment differences were observed in lymphocyte proliferation (Table 6).
NK cell cytotoxicity. NK cell cytotoxicity showed no significant differences in NK cell killing efficiency among treatments (Table 7).

DISCUSSION

This is the first study to address the effects potato consumption on antioxidant status, oxidative stress, inflammation and immune status in humans. Consumption of pigmented

potatoes (YP and PP) decreased 8-OHdG concentrations and IL-6, while consumption of PP also decreased CRP concentrations, decreased Tc cells and increased B cells when compared to WP.

Although fasting total antioxidant capacity did not increase, it appears that YP and PP helped prevent oxidative stress associated with DNA damage. Participants in YP and PP had significantly lower concentrations of 8-OHdG, a biomarker of DNA damage. Pool-Zobel et al. (38) reported a significant decrease in DNA damage in healthy males after supplementation with fruit and vegetable juices high in β-carotene, α-carotene, lutein and lycopene. In the present study, healthy males supplemented for 6 wk with 150 g of potatoes high in carotenoids or anthocyanins had reduced DNA oxidation. Therefore, it is plausible that consumption of yellow and purple potatoes may reduce DNA damage in smokers or individuals with chronic diseases. The prevention of oxidative DNA damage by antioxidants is likely mediated by quenching ROS.

As a biomarker of inflammation, elevated CRP concentrations have recently been implicated in chronic disease development and progression. CRP is produced by the liver in response to the inflammatory cytokine IL-6; reducing circulating CRP can prevent chronic disease development or disease progression. In this study, purple potatoes, a good source of anthocyanins, significantly reduced CRP and IL-6 concentrations in healthy males; plasma IL-6 concentration was significantly lower in YP than in WP. Plasma CRP was about 2-fold lower in YP than in WP, albeit not significantly. The WP demonstrated a non-significant increase in CRP concentrations at wk 6 compared to baseline. These results imply that PP and YP consumption could potentially alleviate inflammatory symptoms associated with chronic diseases such as cardiovascular disease, rheumatoid arthritis, and inflammatory bowel diseases. Antioxidants likely decrease inflammation by down-regulating the pro-inflammatory NFκB gene, which is responsible for cytokine production in immune cells. Reduced plasma IL-6 concentrations will therefore inhibit IL-6-stimulated CRP production by the liver.

The total antioxidant status of our study participants was only marginally affected by potato supplementation. This result was surprising because a preliminary study in our laboratory indicated that plasma antioxidant status increased by 160% measured 6 h after consumption of 300 g of purple potatoes. Anthocyanins are absorbed into plasma within 15-60 min after consumption; urinary excretion is complete within 6-8 h and typically less that 1% of ingested anthocyanins are absorbed. In this study, fasting blood samples were taken at least 14 hr after potato consumption; therefore, the discrepancy in plasma antioxidant status between the two studies is likely due to the low absorption and rapid clearance of anthocyanins from the blood stream. Compliance was not considered an issue in this study, therefore decreases in oxidative damage and inflammation observed in this study may be attributed to phenolic acid, carotenoid or anthocyanin concentrations from the potatoes.

Analysis showed that all potato cultivars contain high concentrations of total phenolics. As expected, the yellow potatoes had highest concentrations of toatal carotenoids while the purple potatoes had high anthocyanin concentrations.

The beneficial effects of carotenoid antioxidants on immune function have been well documented. The Tc population in the PP was significantly lower compared to WP, whereas the B cell population was significantly higher. No other significant changes in lymphocyte subsets were observed among the potato treatments, and all lymphocyte percentages were within normal range. These results imply that anthocyanins from purple potatoes may decrease Tc cell but increase B cell subpopulations.

In conclusion, consumption of yellow and purple potatoes decreased DNA oxidative damage and inflammation associated with IL-6 production. In addition, consumption of purple

potatoes decreased concentrations of the acute phase protein, CRP. The potential physiological benefits of consuming pigmented potatoes should be explored in persons with chronic disease.

TABLE 1
Demographic characteristics of participants

	WP	YP	PP
Age (y)	21.4 ± 1.0	23.1 ± 1.4	22.4 ± 1.4
BMI (kg/m^2)			
Week 0	25.0 ± 1.1	25.8 ± 1.1	25.4 ± 1.0
Week 6	25.1 ± 1.1	25.9 ± 1.1	25.2 ± 1.1
Ethnicity (*n*)			
Caucasian	11	11	10
Asian	1	1	2
Caloric intake, kcal/d	2579 ± 141[a]	2620 ± 141[a]	2100 ± 141[b]

[a, b] Different letters represent significant treatment differences ($P < 0.05$) as analyzed by ANOVA (n =12). Values are mean ± SE.

TABLE 2
Estimated average daily intake of bioactive compounds based on 150 g potato consumed

Treatment	Total phenolics[1]	Total carotenoids[2]	Total anthocyanins[1]	Total antioxidant activity[1]
White	49.6	43.0	0.0	39.7
Yellow	72.9	1323.8	6.8	125.3
Purple	83.2	34.9	166.3	225.4

[1] mg/150 g cooked potato
[2] µg/150 g cooked potato

TABLE 3
Oxidative stress biomarkers in participants fed white (WP), yellow (YP), or purple (PP) potatoes for 6 wk[1, 2]

Treatment	TAC (mM)	Protein carbonyl (nmol/mL)	TBARS (μM)
WP	1.9 [a]	5.6 [a]	1.1 [a]
YP	2.2 [a]	6.3 [a]	1.1 [a]
PP	2.2 [a]	6.5 [a]	1.1 [a]
Overall SE	0.1	0.2	0.1

[1]Data were analyzed by ANCOVA (n =12) using wk 0 as a covariate.
[2] There were no significant treatment differences.

TABLE 4
Plasma cytokine concentrations (pg/mL) in participants fed white (WP), yellow (YP), or purple (PP) potatoes for 6 wk.[1]

Treatment	IL-1α	IL-1β	IL-2	IL-4	IL-6	IL-8	IL-10	IFN-γ	TNF-α
WP	10.6	38.8	23.8	24.4	30.2 [a]	5.2	14.6	3.6	15.4
YP	11.6	40.8	23.8	23.2	16.6[b]	3.8	13.0	3.6	15.0
PP	10.8	39.0	24.4	25.2	16.8[b]	4.4	12.8	4.0	15.0
Overall SE	0.3	0.7	0.4	0.5	3.0	0.4	0.6	0.6	0.4

[1]Data were analyzed by ANCOVA (n =12) using wk 0 as a covariate.
[a, b] Different letters denote significant difference ($P < 0.08$).

TABLE 5
The percent of lymphocyte subsets in participants fed white (WP), yellow (YP), or purple (PP) potatoes for 6 wk.[1]

Treatment	B	Total T	Th	Tc	Th:Tc ratio	NK cells
WP	6.7 [a]	64.3	30.6	28.5 [a]	1.2	24.3
YP	6.5 [a]	68.3	35.8	28.5 [a]	1.3	20.6
PP	9.3 [b]	60.4	30.0	25.0 [b]	1.3	26.3
Overall SE	0.5	1.5	1.3	0.6	0.1	1.3

[1] Data were values were analyzed by ANCOVA (n = 12) using wk 0 as a covariate.
[a, b] Different letters denote significant difference ($P < 0.05$).

TABLE 6
Mitogen-induced lymphoproliferation (cpm) in participants fed white (WP), yellow (YP), or purple (PP) potatoes for 6 wk.[1, 2]

Treatment	PHA, 100 mg/L	PHA, 20 mg/L	ConA, 100 mg/L	ConA, 20 mg/L	PWM, 50 mg/L	PWM, 10 mg/L
WP	17456	3574	14846	9483	4080	3661
YP	16199	3981	15201	10190	5094	5079
PP	15672	4740	12930	8015	3688	3413
Overall SE	1360	757	1009	838	453	475

[1]Data were analyzed by ANCOVA (n =12) using wk 0 as a covariate.
[2] No significant treatment difference ($P < 0.05$) in lymphoproliferation was observed.

TABLE 7
NK cell cytotoxicity (% killing) in participants fed white (WP), yellow (YP), or purple (PP) potatoes for 6 wk.[1, 2]

Treatment	Target : Effector cell ratio	
	(1:1)	(1:5)
WP	97.7	78.2
YP	96.7	86.3
PP	91.2	82.8
Overall SE	4.2	2.6

[1]Data were analyzed by ANCOVA (n =12) using wk 0 as a covariate.
[2] No significant treatment difference ($P < 0.05$) in NK cytotoxicity was observed.

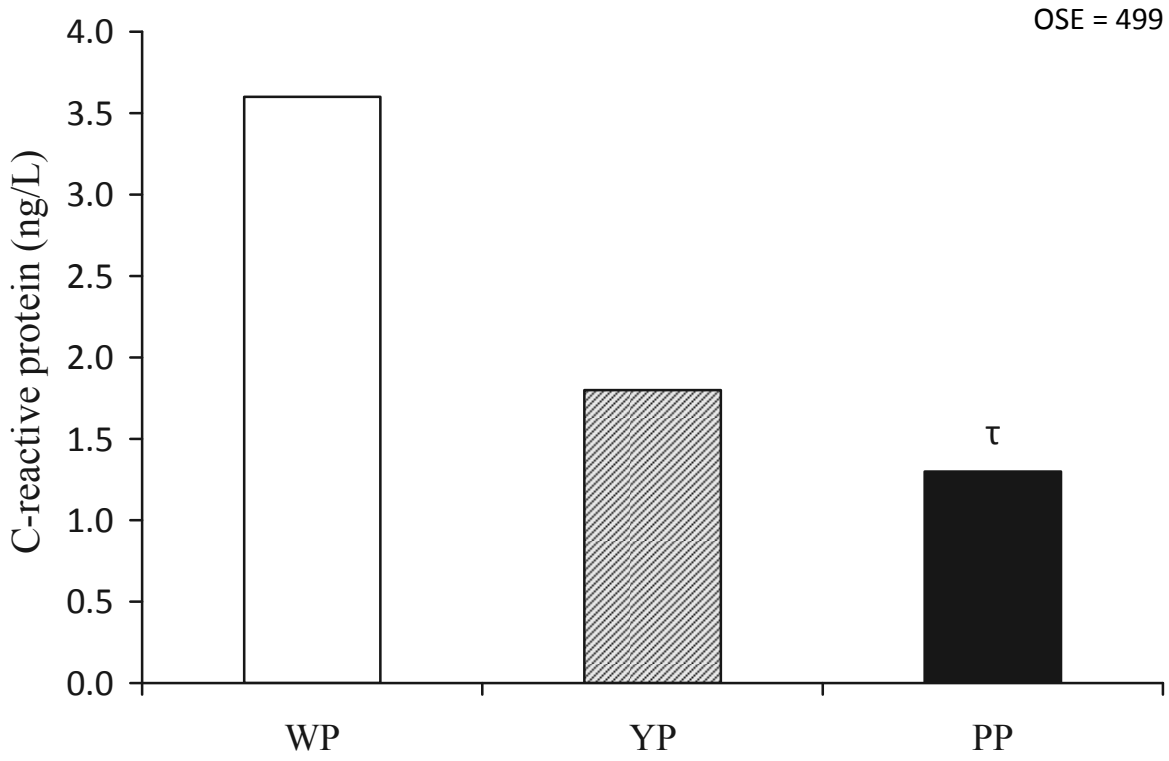

Figure 1. Plasma CRP concentrations in subjects fed white (WP), yellow (YP) or purple (PP) potatoes for 6 wk. Data were analyzed by ANCOVA using wk 0 as a covariate. Different symbols above each bar denote significant difference compared to WP ($^{\tau}P < 0.08$).

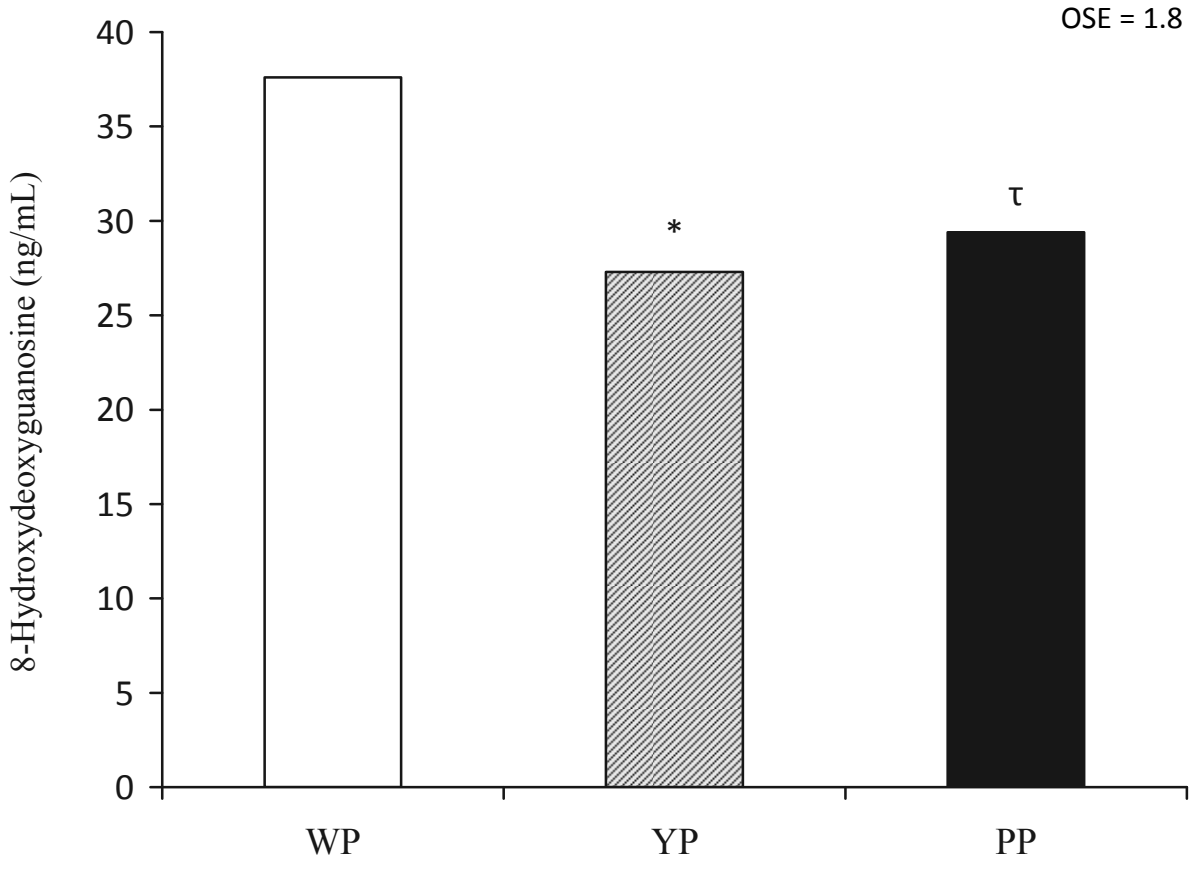

Figure 2. Plasma concentrations of 8-hydroxydeoxyguanosine in subjects fed white (WP), yellow (YP) or purple (PP) potatoes for 6 wk. Data were analyzed by ANCOVA using wk 0 as a covariate. Different symbols above each bar denote significant difference compared to WP ($^{*}P < 0.05$, $^{\tau}P < 0.08$).

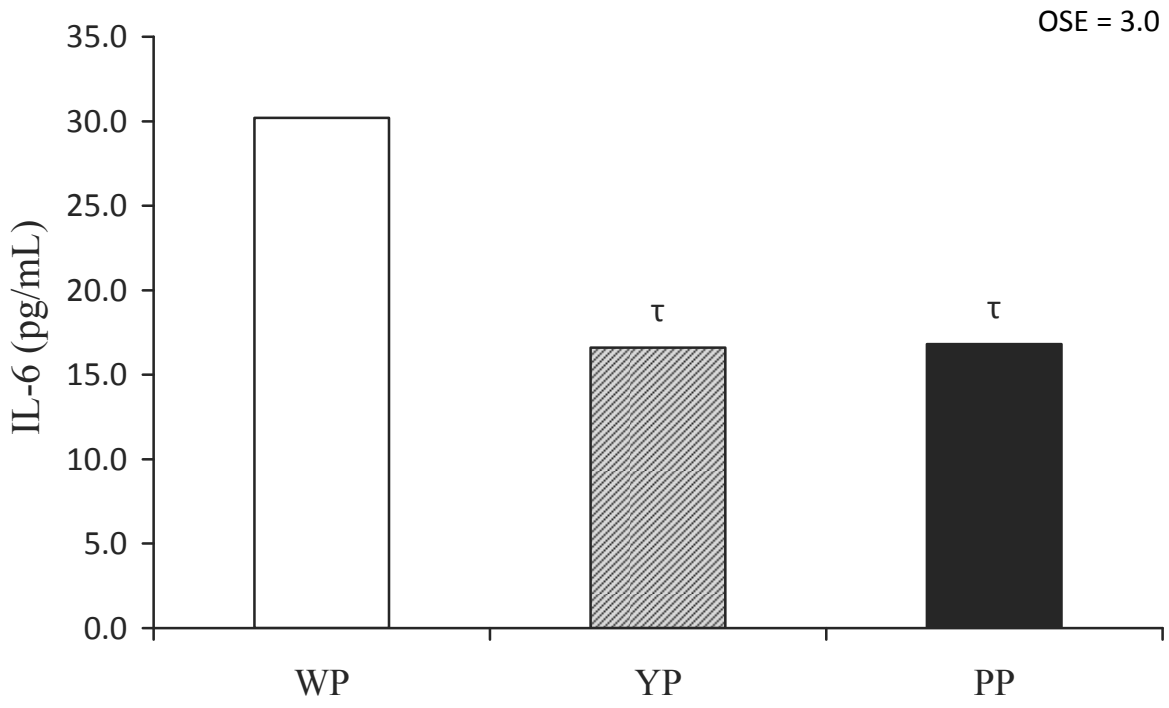

Figure 3. Plasma concentrations of IL-6 in subjects fed white (WP), yellow (YP) or purple (PP) potatoes for 6 wk. Data were analyzed by ANCOVA using wk 0 as a covariate. Different symbols above each bar denote significant difference compared to WP ($^{\tau}P < 0.08$).

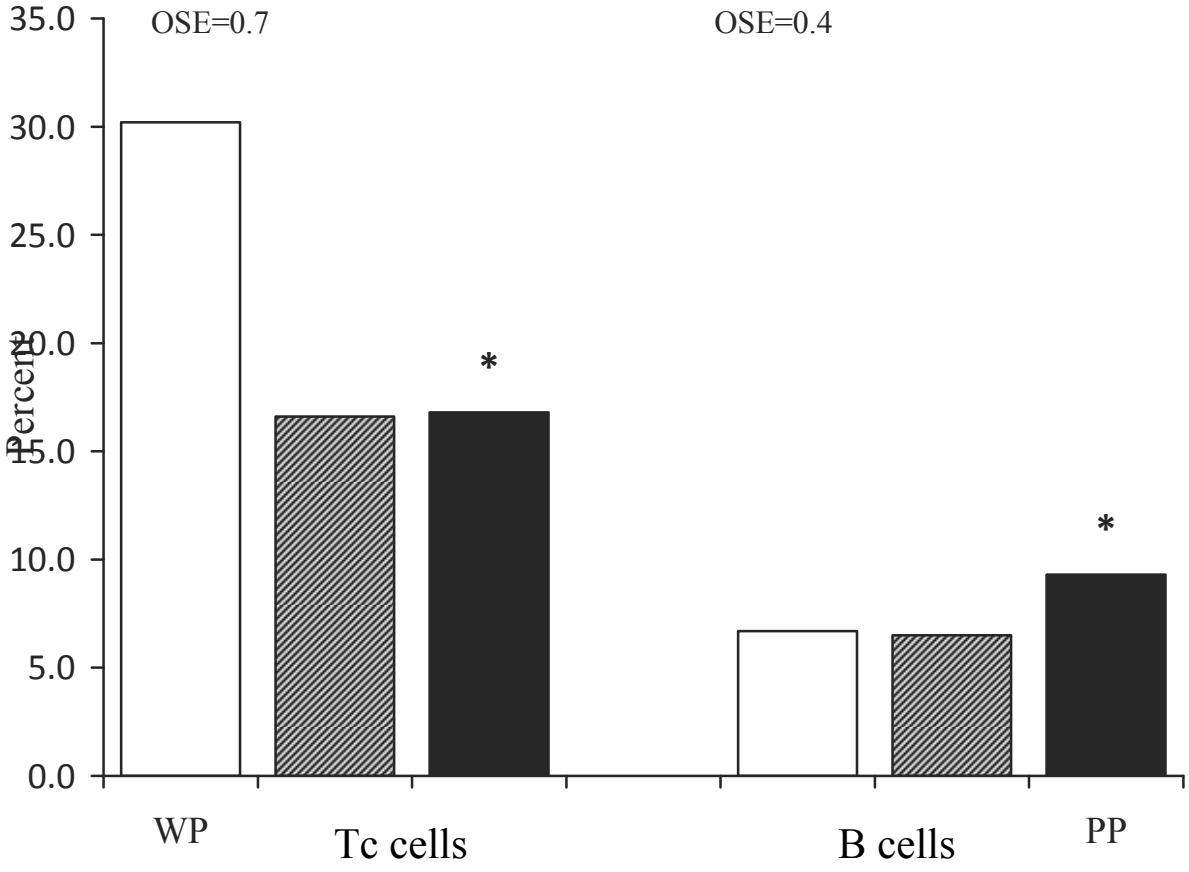

Figure 4. Percent lymphocyte Tc and B cells in subjects fed white (WP), yellow (YP) or purple (PP) potatoes for 6 wk. Data were analyzed by ANCOVA using wk 0 as a covariate. Different symbols above each bar denote significant difference compared to WP ($^{*}P < 0.05$).