Red wine extract disrupts Th17 lymphocyte differentiation in a colorectal cancer context

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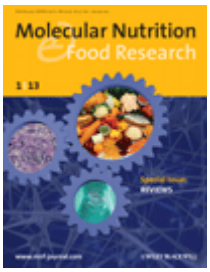

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Complete List of Authors:	Chalons, Pauline; Inserm U1231, Lipids, Nutrition, Cancers Courtaut, Flavie; Inserm U1231, Lipids, Nutrition, Cancers Limagne, Emeric; Inserm U1231, Lipids, Nutrition, Cancers; Centre Georges-François Leclerc, Plateforme de Transfert en Biologie du Cancer (PTBC) Chalmin, Fanny; Inserm U1231, Lipids, Nutrition, Cancers Cantos-Villar, Emma; Instituto de Investigación y Formación Agraria y Pesquera Richard, Tristan; University of Bordeaux Auger, Cyril; UMR 1260 INSERM Nanomédecine Régénérative Chabert, Philippe; UMR CNRS 7021 Schini-Kerth, Valérie B; Université Louis Pasteur de Strasbourg , UMR 1260 INSERM Nanomédecine Régénérative Ghiringhelli, F; Inserm U1231, Lipids, Nutrition, Cancers; Centre Georges-François Leclerc, Plateforme de Transfert en Biologie du Cancer (PTBC) Aires, Virginie; Inserm U1231, Lipids, Nutrition, Cancers Delmas, Dominique; Inserm U1231, Lipids, Nutrition, Cancers
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Red wine extract disrupts lymphocyte Th17 cells differentiation in a cancerous context

Pauline Chalons[1,2], Flavie Courtaut[1,2], Emeric Limagne[1,2,3], Fanny Chalmin[1,2] Emma Cantos-Villar[4], Tristan Richard[5], Cyril Auger[6], Philippe Chabert[7], Valérie Schini-Kerth[6], François Ghiringhelli[1,2,3,8], Virginie Aires[1,2] and Dominique Delmas[1,2*]

[1] Université de Bourgogne Franche-Comté, Dijon, F-21000, France

[2] INSERM Research Center U1231 – Cancer and Adaptative Immune Response Team, Dijon, F-21000, France

[3] Plateforme de Transfert en Biologie du Cancer (PTBC) Centre Georges François Leclerc, Dijon, F-21000, France

[4] Instituto de Investigación y Formación Agraria y Pesquera (IFAPA) Rancho de La Merced, Ctra. Trebujena, 11.471 Jerez de la Frontera (Cadiz), Spain

[5] Université de Bordeaux, Unité de Recherche Œnologie, EA 4577, USC 1366 INRA, Equipe Molécules d'Intérêt Biologique - ISVV, Villenave d'Ornon, F-33882, France

[6] UMR 1260 INSERM Nanomédecine Régénérative, Université de Strasbourg, Illkirch, F-67401, France

[7] UMR CNRS 7021 - Laboratoire de Bioimagerie et Pathologies - Université de Strasbourg, Illkirch-Graffenstaden, F-67401, France

[8] Department of Medical Oncology, Centre Georges François Leclerc, Dijon, F-21000, France

*Correspondence: dominique.delmas@u-bourgogne.fr, Tel.: +33-380 39 32 26

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Abstract

Scope

It is well established that immune response and inflammation promotes tumoral progression. Immune cells communicate through direct contact or through cytokine secretion and it is the expression of those mediators and of the pro-inflammatory status that will tip the balance towards tumor progression or anti-tumor immunity. We have recently demonstrated that a red wine extract (RWE) was able to decrease inflammation through an action on the NLRP3 inflammasome complex. This study determined whether a RWE impacts other key actors of inflammation through an action on immune Th17 cells.

Methods and Results

Using a RWE containing 4.16g of polyphenols per liter of wine, we showed *in vitro* and *in vivo* that RWE exerts a reduction of tumor growth associated with a decrease of the tumor-infiltrating lymphocytes. More specifically, the process of lymphocyte T differentiation into protumoral Th17 cells was altered by RWE *in vitro* and *in vivo* as revealed by the decrease in key actors' expression controlling this process such as STAT3 and RORγt. Subsequently, this disruption was associated with an inhibition of inflammatory IL-17 secretion.

Conclusion

The result highlighted the main involvement of Th17 immune cells in the biological effect of a red wine extract.

1. Introduction

For several years, numerous epidemiological studies have shown that there is a strong link between inflammation and the immune system. Indeed, immune cells play a role in first-line defense following various traumas caused by infectious agents, chemical substances, physical agents or even post-traumatic tissue lesions. In contrast, inflammation has been described as an initiator event of major diseases with a significant impact in terms of public health such as cardiovascular diseases, autoimmune diseases, eye diseases, age-related diseases, and more particularly neurodegenerative diseases and the occurrence and development of cancers. In this last context, tumoral cells can produce various chemokines through different process. Among the most well-known processes, the release of interleukin-1 beta (IL-1β) following the activation of a multiprotein complex, the inflammasome, is responsible for inflammation that can be acute but also chronic or low-noise, causing many disorders including the occurrence of cancers. A second well-known process is the secretion of pro-inflammatory interleukins by immune cells that are able to overproduce various factors promoting proliferation, inflammation, neoangiogenesis. Among these proteins, we found IFN-γ, TNFα, IL-6, IL-17A, and IL-25 that strongly contribute to tumoral growth.

Therefore, one of the major current issues would be to find compounds capable of modulating these production processes of pro-inflammatory substances and thus help reduce the occurrence of pathologies or reduce their progression. In this way, various studies have pointed the interest of polyphenolic compounds to prevent various diseases without toxicities. For example, numerous studies reveal that phytoconstituents or micronutrients can protect against cancers [1]. Especially, Levi et al. show an inverse relation between resveratrol (a non-flavonoid polyphenol) and breast cancer risk [2]. Another cohort study in Finland [3] shows a link between flavonol consumption and reduced risk of lung cancer. These findings lead to the suggestion that polyphenols and flavonoids have beneficial health effects. Very

recently, we have highlighted the potential anti-inflammatory effect of an extract of red wine enriched in polyphenol compounds (RWE) on macrophages [4]. This extract was able to strongly decrease IL-1β secretion through a modulation of the expression of key proteins involved in the inflammasome complex, i.e., NLRP3 and apoptosis-associated speck-like protein containing a CARD (ASC). Moreover, we have demonstrated that RWE disrupted the priming signal and the activating signal leading to inflammasome activation in macrophages [4]. This important way could then prevent inflammation in various contexts, but at present there is no data on the effect of a complex mixture such as a polyphenol-rich red wine extract on the immune response and its involvement in tumor progression.

Considering the fundamental role playing by the lymphocytes T in cell-mediated immunity, and more particularly by the lymphocytes T helper (Th cells) are also known as $CD4^+$ T cells, we investigated the potential effect of a red wine extract (RWE) on Th17 immune cells that have inflammatory properties derived from their ability to produce various interleukins (i.e. IL-17A, IL-17F, IL-6, IL-21, IL-22 and TNFα). We demonstrated that RWE-enriched in polyphenolic compounds reduced colorectal tumoral growth in mices which was associated with a decrease of the percentage tumor-infiltrating lymphocytes. These effects involve an alteration of the lymphocyte T differentiation into pro-inflammatory Th17 cells where the key regulators of this process, the proteins RORγt (Retinoid-related Orphan Receptor gamma t) and STAT3 (Signal Transducer and Activator of Transcription 3), where affected by RWE treatment. Subsequently, this disruption of Th17 polarization leads a strongly decrease of pro-inflammatory IL-17 secretion and underlines the potential anti-inflammatory properties of complex mixture of polyphenol compounds.

2. Materials and Methods

2.1. Cell lines

Human colorectal cancer cell lines SW620, HCT116 and murine colorectal cancers CT26 and MC38 were obtained from the American Type Culture Collection. Cells were maintained in a 5% CO_2 humidified atmosphere at 37°C and cultured in DMEM supplemented with 10% (v/v) fetal calf serum (Dutscher). Cells were routinely tested for mycoplasma contamination using the Mycoalert Mycoplasma Detection Kit (Lonza).

2.2. Preparation of red wine extract

Red wine extract (RWE) was obtained from French red wine, Santenay 1er cru Les Gravières 2012 (Côte d'Or, France) selected by the BIVB (Bureau Interprofessionnel des Vins de Bourgogne) and provided by CTIVV (Centre Technique Interprofessionnel de la Vigne et du Vin). Red wine extract dry powder was prepared and analyzed as previously described [5]. Briefly, phenolic compounds were adsorbed on a preparative column, then alcohol desorbed. The alcoholic eluent was gently evaporated, and the concentrated residue was lyophilized and finely sprayed to obtain the phenolic extract dry powder. Briefly, the alcoholic eluent and water were gently evaporated using a rotary evaporator set, and the concentrated residue was deposited on the column (Diainon® HP-20). The reservoir was filled with distilled water and the flow was adjusted to about 20 drops/min. The polyphenol fraction was eluted with an ethanol-0.1% glacial acetic acid solution (flow adjusted to 40 drops/min). The individual eluent fractions were collected and concentrated to dryness using a rotary evaporator set. One liter of red wine produced 104 g of phenolic extract, which contained 5.04 mg/g of total phenolic compounds expressed as gallic acid equivalent.

2.3. HPLC analysis

The phenolic composition of the wine samples was determined by HPLC analysis according to the method Guererro *et al.* [6]. Briefly, HPLC analysis was performed on a HPLC system equipped with a diode array detector, a fluorescence detector and a C18 column (5 µm, 250 mm × 4.6 mm) for compound separation. For anthocyanins and flavonols, the mobile phase

consisted of water containing 5% formic acid (v/v) and methanol in various proportions at a flow rate of 1 mL/min. Anthocyanins were quantified at 520 nm as malvidin-3-glucoside and flavonols at 360 nm as quercetin-3-rutinoside. Flavan-3-ols and phenolic acids were analyzed using a gradient containing water with 2% acetic acid (v/v) and methanol–water–acetic acid (90:8:2, v/v/v). Phenolic acids were quantified at 320 nm as caffeic acid, flavan-3-ols as catechin using the fluorescence signal (excitation wavelength, 290 nm; emission wavelength, 320 nm) and stilbenes as resveratrol (excitation wavelength, 330 nm; emission wavelength, 320 nm).

2.4. Cell proliferation and viability measurements

Human and murine colorectal cancer cells were seeded in sextuplicate into 96 well-plates ($1.5x10^4$ cells per well) and treated for 48 and 72h at 37°C with increasing concentrations of RWE (from 1.9 to 250 µg/mL). At the end of the treatments, cells were washed with PBS, stained for 5 min with a crystal violet solution (0.5% (w/v) crystal violet in 25% (v/v) methanol) and then gently rinsed with water. Absorbances were read at 540 nm with a Biochrom Asys UVM 340 spectrophotometer, after the extraction of the dye by 0.1 M sodium citrate in 50% ethanol. The inhibitory concentrations 50 % (IC_{50}) were calculated by a 4-parameter nonlinear regression with SigmaPlot version 6 software (Systat software, Inc).

2.5. Apoptosis identification

Apoptosis was determined using the annexin V-FITC and 7-aminoactinomycin D (7AAD) staining from BD Biosciences according to the manufacturer's instructions. Briefly, cells were seeded in 12-well plates (5.10^4 cells/well) 24 h before treatments. The following day, cells were treated with the indicated concentrations of RWE for 48 and 72 h. At the end of the treatments, cells were harvested, washed two times with cold PBS and then incubated for 15 min at room temperature with a mixture of annexin V-FITC/7AAD (5 µL each per sample) in 50 µL of binding buffer. At the end of the incubation, 100 µL of binding buffer was added

and cells were kept on ice until analysis. Annexin V binding and 7-AAD incorporation were detected by an LSRII flow cytometer (BD Biosciences) and analyzed using Flowjo software (Tristar, Ashland, OR, USA).

2.6. Mouse strains

Six-week-old BALB/c and C57BL/6Rj female mice were purchased from Janvier Labs (Saint-Berthevin, France). All mice were housed and maintained 22-24°C on a 12-h light-dark cycle in a designated pathogen-free area accredited by the Federation of Laboratory Animal Science Associations (FELASA). All experiments involving mice were performed in accordance with the institutional guidelines and were approved by the University of Burgundy's Ethics Committee on the Use of Laboratory Animals. Animals were provided *ad libitum* access to a chow diet.

2.7. Tumor growth experiments

Eight-week-old BALB/c mice were randomly divided into two experimental groups (14 mice per group). Mice were individually maintained on normal chow (control mice group) or fed *per os* with 100 mg/kg/day of RWE (RWE mice group), for three weeks prior to the induction of tumor formation and throughout tumors growth. To induce tumor formation, 4×10^5 mycoplasma free CT26 cancer cells were injected subcutaneously into the left flank of balb/c mice. Tumor size was monitored three times a week by caliper measurements of the widest diameter and the narrowest diameter. Time of death was considered when mice reached experimental endpoints related to graft size, animal weight and general behavior in accordance with the guidelines prescribed by the Ethics Committee at the University of Burgundy.

2.8. Isolation and analysis of tumor-infiltrating lymphocytes (TILs)

Xenograft tumors from mice groups (4 per group) described in the previous section were harvested 12 days after tumor formation induction and then dissociated in RPMI with the

gentleMACS™ dissociator (Myltenyi Biotec) according to the manufacturer's protocol. Lysates were centrifuged and cells were stained with an antibody cocktail containing anti-CXCR3-BV421 (CXCR3-173, BD Biosciences), anti-CD4-VioBright FITC (REA604, Miltenyi Biotech), anti-CD45RA-APC-Vio770 (30F11, Miltenyi Biotech) and anti-CCR6-PE (REA277, Miltenyi Biotech). Tumor infiltrating Th17 cells were identified as $CD4^+$, $CD45RA^-$, $CCR6^+$, $CXCR3^-$. After surface staining, 2 Ml of red blood cells lysis solution (BD Biosciences) was added for 10 minutes, centrifuged (400 x g, 5 minutes) and then resuspended in flow cytometry buffer (eBioscience). All events were acquired by a BD LSR-II cytometer equipped with BD FACSDiva software (BD Biosciences), and data were analyzed using FlowJo software (Tree Star). The gating strategy is illustrated in Figure 5A.

2.9. In vitro Th17 cells differentiation

Naïve $CD4^+$ T cells ($CD4^+$ $CD62L^{hi}$) were obtained from spleens and lymph nodes of C57BL/6Rj mice. $CD4^+$ T cells were purified from spleen and lymph nodes with anti-CD4 microbeads (Miltenyi Biotec), then were further sorted as naïve $CD4^+CD62L^{hi}$ T cells. Isolated naïve T cells were routinely 98% pure. Isolated naïve $CD4^+$ T cells were stimulated with plate-bound antibodies against CD3 (145-2C11, 2 µg/mL; BioXCell) and CD28 (PV-1, 2 µg/mL; BioXCell) and polarized into effector $CD4^+$ T lymphocyte subsets with cytokines. Mouse, IL-6 (25 ng/mL), and TGF-β (2 ng/mL) were all purchased from MiltenyiBiotec. Anti-IL-4 (clone 11B11; 10 µg/mL) and anti-IFNγ (clone XMG1.2; 10 µg/mL) antibodies were obtained from Bio-XCell. In experiments, RWE have been added at the final concentrations of 0.2, 2, 20 and 100 µg/ml. As previously described, cells were classically harvested on day 3 (unless otherwise specified) for detection of cytokines by ELISA and for quantitative real-time PCR (qRT-PCR) analysis as previously described [7].

2.10. Measurement of IL-17A production

After a 72-hour polarization, cell culture supernatants were assayed by ELISA for mouse IL-17A (Biolegend), according to the manufacturer's protocol.

2.11. Western Blotting analysis

Purified naïve T cells were differentiated for 6 or 24 hours into Th17 cells with or without RWE, then collected and pelleted by centrifugation (5 minutes, 450g, 4°C). Cells were lysed in boiling buffer [1% SDS, 1 mM sodium orthovanadate, and 10 mM Tris (pH 7.4)] containing protease inhibitor cocktail for 20 minutes at 4°C. Cell lysates were subjected to sonication (10 seconds at 10%) and protein concentration was assessed using the Bio-Rad DC Protein Assay Kit. Proteins were then denaturated, loaded, and separated on SDS-PAGE and transferred on nitrocellulose membranes. After blocking with 5% nonfat milk in Phosphate-Buffered Saline containing 0.1% Tween 20 (PBST), membranes were incubated overnight with primary antibody diluted in PBST containing 5% BSA: rabbit monoclonal antibodies anti-STAT3 and anti-phospho-STAT3-Tyr705 (Cell Signaling Technology), rat monoclonal antibody was used: anti-RORγt (eBiosciences), or mouse monoclonal antibody anti-β-actin (Sigma-Aldrich). Afterwards, the membranes were incubated with antibodies HRP-conjugated polyclonal goat anti-mouse (Jackson ImmunoResearch), polyclonal goat anti-rabbit (Cell Signaling Technology) and polyclonal goat anti-rat (Santa Cruz Biotechnology) at room temperature for 1 h and developed using the ECL reagents (Supersignal West Femto maximum sensitivity substrate, ThermoFisher). Digital chemiluminescence images were captured and analyzed using the ChemiDocTM XRS + imaging system (BioRad). Image processing and analyses were carried out using Image Lab 5.2.1 build 11 Bio-Rad software.

2.12. Quantitative real-time PCR

Total RNA from T cells was extracted with TriReagent (Ambion), reverse transcribed using M-MLV Reverse Transcriptase (Invitrogen), and was analyzed by RT-qPCR with the SYBR Green method according to the manufacturer's instructions using the 7500 Fast Real-Time

PCR System (Applied Biosystems). Expression was normalized to the expression of mouse or human *Actb*. Primers designed to assess gene expression are as follows: *Actb mus musculus* 5′-atggaggggaatacagccc-3′ and 5′-ttctttgcagctccttcgtt-3′; *il17a mus musculus* 5'-tgagcttcccagatcacaga-3' and 3'-tccagaaggccctcagacta-5' and *il17f mus musculus* 5′-ttgatgcagcctgagtgtct-3′ and 3'-aattccagaaccgctccagt-5.

2.14. Statistical analysis

Results are shown as means ± SD for triplicate assay samples (otherwise mentioned), reproduced independently at least three times. Statistical analysis of data was carried out with Prism GraphPad6.0 Prism Software. The significance of the differences between mean values was determined by a one-way ANOVA with Holm-Sidak correction. *P*-values <0.05 were considered significant ($*p < 0.05$, $**p < 0.01$ and $***p < 0.001$). For *in vivo* studies, mice survivals were estimated by the Kaplan-Meier method and were compared by the log-rank test.

3. Results

3.1. RWE decreases colorectal cancer cells proliferation

We have previously shown that red wine extract (RWE) can decrease the number of colonic aberrant crypt foci (AFC) in the CF-1 mouse model for AOM induced preneoplastic colonic AFC [8] suggesting the potential interest of polyphenol extract from red wine in a precancerous context. In order to better understand the potential effects of RWE, we investigated its effects on immune cells in colorectal cancer context. Indeed, it is now clearly established that a modulation of specific immune cells can influence the development or regression of cancers. To determine the potential effect of RWE on immune cells, we have collected a French red wine, Santenay 1er cru Les Gravières 2012 (Côte-d'Or, France) from which we made a dry extract enriched in polyphenols that we so-called Red Wine Extract

(RWE). In order to appreciate its polyphenolic content, we performed a qualitative and quantitative analysis by HPLC of RWE. As shown in figure 1, RWE showed high levels of phenolic acids (caftaric acid, caffeic acid), anthocyanidins (malvidin), catechins (catechin and procyanidin dimers), stilbenes (resveratrol and its glycosylated form piceid) and flavonols (quercetin). These contents are important to consider since we have previously shown that the qualitative and quantitative composition of bioactive compounds of the wine could influence the biological effects of this one. In particular, we showed that there was a synergistic effect against the proliferation of colon cancer cells resulting from an association between resveratrol and quercetin [8]. This effect is no longer additive for a combination of resveratrol / catechin or resveratrol / catechin / quercetin. Histogram of figure 1 reveals that a high level of total resveratrol (1.92 mg/g of RWE) and quercetin (0.96 mg/g of RWE) as compared to our previous studies [8], suggesting a potential benefit effect to induce the death of colon cancer cells. In this way, we first evaluated the RWE toxicity in our models of colon cancer cell lines (Fig. 2). Human colorectal metastatic cancer cells SW620, colorectal carcinoma cells HCT116 and murine colorectal cancer cells MC38 and CT26 were exposed to various concentrations of RWE (0.1 to 250 µg/mL) during 48 and 72 h (Fig. 2A, B). As revealed by the cytotoxic curves, RWE presented a cytotoxic activity in all colorectal cancer cell lines tested in time and concentration-dependent manner. Indeed, the inhibitory concentration of 50 % of tumor cells (IC_{50}) is more lower in human cancer cell lines after 48h of treatment than murine colorectal cancer cells (Table I), but this difference fades to 48 hours of treatment. Secondly to determine whether these antiproliferative effects of RWE are associated with an induction of cell death, we analyzed the RWE impact on apoptosis process. To highlight this, cancer cell lines were double staining with Annexin V / 7 AAD after treatment with 100 and 200 µg/mL of RWE. Consistent with cytotoxicity curves, results show that polyphenol extract induced at early time of 48h treatment a more apoptosis in human colorectal cancer cells

SW620 and HCT116 as compared to murine colorectal cancer cells MC38 and CT26 for which there are no significant differences from the control (Fig. 3A). However, at 72h we observe a strong induction of death in all colon cancer cell lines with a sharp increase in the rate of late apoptosis (Fig. 3B).

3.2. RWE decreases colorectal tumor progression in xenogreffed mice model

In a second step, we sought to correlate the inhibitory effects of proliferation and induction of apoptosis *in vitro* with the ability of RWE to prevent tumor progression. In order to demonstrate this, C57 BL6 mices received a fixed amount of RWE (100 mg/kg/days) for 3 weeks before receiving subcutaneous murine tumoral colon CT26 cells. Our results showed that RWE delays the growth of tumors as early as five days after tumor implantation as compared to the tumoral growth of mice controls (Fig. 4A). This difference is sharply accentuated 15 days after the injection of CT26 cells (Fig. 4A). This regression of tumor growth induced by RWE is associated with a significantly increase of survival rate in mice receiving RWE complementation (Fig. 4B).

3.3. RWE disturbs tumor-infiltrating lymphocytes

To precise the relationships between antitumoral effect of RWE and the immune cells, we evaluated the percentage of tumor-infiltrating lymphocytes. Among T lymphocytes coexist many T cell populations that are not homogenous where each subgroups present specific function and structure. We have recently shown that resveratrol was able to affect lymphocyte Th17 differentiation and subsequently disrupts interleukin-17 (IL-17) production [7]. These resveratrol effects were associated with a reduction in various *in vivo* models of tumor growth and metastasis [7]. Due to this importance of Th17 in the biological response of some polyphenols, we have investigated whether RWE could affect more specifically the $CD4^+$ Th

cells. To further analyze these immune cells, we use polychromatic flow cytometry to sort $CD4^+$ T cells subsets with differential expression of CD45, CXCR3 and CCR6. We observed that after 3 weeks of RWE treatment, a decreases of the percentage of tumor-infiltrating lymphocytes ($CD45^+CD4^+CXCR3^-CCR6^+$) in tumor at 12 days after inoculation of tumor (Fig. 5). This significant reduction of RWE-induced TIL reduction is associated with a decrease of IL-17 as measured by ELISA method in plasma level of mice treated by RWE (not shown).

3.4. RWE counteracts IL-17 production and genes expression

Among CD4 activated cells, specific markers CXCR3-CCR6+ characterized Th17 that specific immune cells critical for progression of cancer through the production of various pro-inflammatory cytokines we identified the Th17 such as IL-6, IL1, IL-8 and IL-17. This last interleukin is responsible firstly for chronic and acute inflammation contributing to tumoral growth but secondly this interleukin promotes tumor angiogenesis through the stimulation of vascular endothelial growth factor (VEGF) by both tumoral cells and fibroblasts. To corraled precise the RWE effect on the specific imune T cells Th17 and its main itnerluekin 17 secretion, we have isolated naive T cells from lymph nodes and mice spleen, then they were diffrentiated *invitro* into pro-inflammatory Th17 with a cocktail of specific csytokines with or without various concentration of RWE during 3 days. Using ELISA method, we measured IL-17 secretion which is strongly decreases with RWE treatment in a dose dependent manner as compared to the control (Fig. 6A). This inhibition of IL-17 secretion is associated with a decrease of genes encoding this interleukin, RWE being also able to decrease mRNA levels of *il-17A and iL-17F* genes (Fig. 6B).

3.5. Alteration of lymphocytes T differentiation by RWE *in vitro* and *in vivo*

Differentiation of lymphocytes T is mainly under the control of signaling pathway involving key proteins such as the homodimer STAT3 and the nuclear transcriptional factor RORγt. In fact, the phosphorylation of STAT3 stabilizes the protein. Once phosphorylated, STAT3 is translocated into the nucleus to active the transcription of gene encoding the protein RORγt which in turn will activate the transcription of genes encoding interleukins, particularly IL-17. As previously, immunoblotting of Th17 from *in vitro* differentiation of naive T cells reveals that a RWE treatment during three days decreases phosphorylation of STAT3 and subsequently strongly decreases RORγt protein expression in concentration-dependent manner (Fig. 7A & B). In order to evaluated whether RWE could affect the lymphocyte T cells differentiation in animal models, we have pretreated mice with (100 mg/kg/days) for 3 weeks, and we have isolated as previously naive T cells from lymph nodes and mouse spleen before their *in vitro* differentiation into Th17. Interestingly, immunoblotting highlight that RWE treatment during 3 weeks significantly decreases RORγt protein expression ($p<0.05$) and therefore the ability of naïve T cells to differentiate into pro-inflammatory Th17 (Fig. 7C & D).

4. Discussion

In the present report, we studied the effects of a red wine extract (RWE) rich in polyphenolic compounds on the immune lymphocyte T cells *in vitro* and *in vivo* and the link with the antitumoral properties of polyphenol extract. We found that antitumoral effects of RWE *in vivo* are associated with significant reduction of the percentage of tumor-infiltrating lymphocytes (TILs). These lymphocytes play often a dual role in the balance between pro- and anti tumoral effects. Thus, we highlight that RWE affects lymphocytes T into specific lymphocytes T helper called Th17 which are able to overproduce a pro-inflammatory interleukin, IL-17. We subsequently showed that RWE reduced IL-17 secretion-associated

pro-inflammatory Th17. The molecular mechanism seems to involve a disruption of a specific signaling cascade where the nuclear transcriptional factor, protein RORγt, which play an essential role in Th17 differentiation is strongly decrease by RWE.

The immune system can recognize many cancers (*i.e.* breast, ovarian, colon cancers). Natural antitumor immunosurveillance fights against the appearance and development of cancers. Thus, it has been shown that local immunological factors may therefore have a positive effect on tumor progression or on the contrary play a deleterious role on tumor progression. Indeed, we have been able to show that a lymphocyte population called regulatory T lymphocytes could inhibit the antitumor immune response in humans as well as in animals [9]. These regulatory T cells are able to inhibit the T dependent immune response and the increase in their number is a factor of poor prognosis in patients with ovarian cancer [10]. Another team has shown that probably only patients with a high infiltration of CD8 effector cells into ovarian tumor and few regulatory T cells would have a good prognosis [11]. Conversely, a deleterious role of inflammation and the immune system is seen added to all these mechanisms that can pervert the immune system including *via* mechanisms involving the production of pro-inflammatory cytokines such as TNFα, IL-6 and IL-1β. These cytokines induce a modification of the T cell polarization towards a Th17 polarization (IL-17 producing cells). This population exerts a protumoral role by increasing tumor angiogenesis and making tumor cells resistant to cell death. Therefore, by decreasing the production of pro-inflammatory substances such as IL 17, RWE is able to reduce tumor growth but also angiogenesis. These results allow us to provide a possible explanation for the observation of many teams including Schini-Kerth's team who showed in a model of colon cancer that red wine extract reduced neoangiogenesis [5]. In fact, the modulation of immune cells could appear as the upstream element of the antitumor effects observed for the RWE but also for many polyphenols. Indeed, we have recently shown that resveratrol was able to modulate

lymphocytes T differentiation into Th17 in similar manner as metformin [7]. The antitumoral effect of resveratrol was dependent of Th17-IL-17 system. Indeed, using IL-17 knock down mices where the antitumoral resveratrol activity observed in normal mice was abolished in IL-17 KO mice [7]. Furthermore, resveratrol effect on the IL-17 production contributes to reduce VEGF levels and subsequently contributes to strongly decrease the number of pulmonary metastasis in tumorigenesis-induced mice [7].

The molecular mechanism of antitumoral effect and more specifically the RWE-induced immunomodulation seems more complicated, because of the relatively complex composition of the mixture (Fig. 1) that contains a high number of polyphenolic compounds that may interact with each other or target various signaling pathway actors. We previously demonstrated that the qualitative and quantitative composition of a wine in bioactive molecules such as polyphenolic compounds is crucial in the biological effects that can be observed and that they are antagonistic or synergistic [8]. We previously showed that resveratrol and quercetin combined exhibited a synergistic effect inducing apoptosis, antiproliferative effects, and cell cycle disruption compared to the compounds alone in colon cancer cells. Interestingly, in this same study, the combination of resveratrol+catechin or resveratrol+catechin+quercetin produced only an additive effect on the inhibition of tumor cell proliferation or on cell cycle arrest, and catechin+quercetin did not induce a synergistic effect on apoptosis [8]. In this way some reports have shown a potential effect of quercetin on Th17 in some models of inflammation. For example, quercetin was able to reduces Th17 cell polarization through an inhibition of a mitogen-activated protein kinase Toll-like receptor 4 (MAPK-TLR4) signaling pathway and subsequently decrease IL-17 production in a model of dental pulpitis [12]. Interestingly, in a model of rheumatoid arthritis using osteoclasts, quercetin reduces Th17differentiation and IL-17-stimulated RANKL (Receptor Activator of Nuclear factor kappa-B Ligand) production in RA-FLS (Rheumatoid Arthritis-Fibroblasts-

Like Synoviocytes) and IL-17-stimulated osteoclast formation [13]. In similar manner, catechin, and more particularly epigallocatechin-3-gallate (EGCG) suppressed expansion and cell cycle progression of naïve $CD4^+$ T by modulating cell cycle-related proteins. EGCG also inhibited naive $CD4^+$ T-cell differentiation into Th1 and Th17 effector subsets by impacting their respective signaling transducers and transcription factors in some models of autoimmune diseases [14-17].

But in the concept of immunosurveillance in a cancerous context, various other immune cells play key roles such as cytotoxic T cells (CTL or $CD8^+$ T cells) that are able to induce the death of infected somatic cells or tumor cells. The activation and differentiation of $CD8^+$ cells is an essential step for the establishment of a response against intracellular pathogens and against tumor cells. For example, in a tumor context, the polyphenol resveratrol led to an increase in the number of cytotoxic T-lymphocyte associated protein 4 (CTLA-4; also known as CD152)-positive cells and in the gene expression levels of CTLA-4, FoxP3, IL-10 and TGF-β these two last TGF-β and IL-10 being anti-inflammatory cytokines and controlling pathogenic, as well as aging-associated inflammatory conditions [18]. In a same manner, other immune cells such as regulatory T cells (Treg cells) appear essential in cancer progression, since the presence of Treg cells is likely to correlate with cancer progression [19], and specific depletion of Treg cells markedly inhibits tumor growth and maintains a strong and persistent antitumor immune response [20]. Again many polyphenols can act on these immune cells [21, 22]. Additional studies are now in progress to determine the impact of a polyphenol-enriched extract on the different subsets of immune cells and more particularly on T cells that play a central role in cell-mediated immunity.

Author contributions : P.C. performed the experiments and analyzed the data; F.C. performed immunological detection; E.L., F.C. performed Th17 isolation; E.C.V. and T.R.

performed HPLC analysis; C.A, P.C. and V.S.K. performed RWE production and analyzed the data; V.A. and F.G. helped in setting up the project and analyzed the data; V.A. and D.D. revised the manuscript; D.D. supervised the overall project.

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Conflicts of Interest: the authors declare no conflict of interest.

5. References

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Legends of figures

Figure 1. HPLC quantification of red wine extract (RWE) obtained from the Santeney 1er cru Les Gravières 2012. The content of compounds was expressed of mg of compound per g of RWE.

Figure 2. Concentration-dependent inhibition of colon cancer cells proliferation by RWE. After 24h of culture, cells were incubated with or without RWE during 48h (A) or 72h (B) at the indicated concentration. The percentage of viable cells was determined by crystal violet assay. Results were expressed as percentage of control (A and B : mean ±SD of three independent experiments with n=6).

Figure 3. RWE-induced apoptosis in colon cancer cell lines. After 24h of culture, SW620, HCT116, MC38, CT26 cell lines were incubated with vehicle (Co) or with RWE (100 or 200 µg/ml) and then were stained with Annexin V/7AAD after 48h (A) or 72h (B). The data are mean ±SD of three independent experiments. *P*-values were determined by the multiple Student's *t*-test. * $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Figure 4. RWE reduced colorectal tumor growth and increased survival level of mice. Eight-week-old C57BL/6Rj female mice daily received *per os* RWE of RWE (100 mg/kg/day; RWE mice group) or the vehicle (control mice group) during 3 weeks before bearing CT26 colorectal tumors (n=10 per group) and for 19 days after initiation of tumor formation. Tumor size in mm^2 over time is represented as median ± s.e.m. B) Kaplan-Meier cumulative survival plots for mice groups described in A), with *p*-values assessed by the log-rank test. * $p<0.05$.

Figure 5. RWE decreases Tumor-Infiltrating Lymphocytes (TILs). Eight-week-old C57BL/6Rj female mice daily received *per os* RWE of RWE (100 mg/kg/day; RWE mice group) or the vehicle (control mice group) during 3 weeks before bearing CT26 colorectal tumors (n=10 per group) and for 12 days after initiation of tumor formation. Xenograft tumors from mice groups (4 per group) were harvested at day 12 and dissociated prior to cell surface staining with specific antibodies and analysis by flow cytometry. The results are expressed in percentage ± s.e.m of infiltrated Th17 cells ($CD4^+$, $CD45RA^-$, $CCR6^+$, $CXCR3^-$) in xenografts tumors from mice groups is shown. *P*-values were determined by the Mann-Whitney U-test. * $p<0.05$.

Figure 6. RWE-induced interleukin 17 inhibition in lymphocytes Th17. $CD4^+$ T cells isolated from draining lymph nodes or mouse spleen from C57bl/6 mice and then they were differentiated into Th17 cells in the presence of anti-CD3 and anti-CD28 for 24h in presence or not of 0.2, 2, 20, 50, 100 and 150 µg/ml of RWE during 3 days. IL-17 A protein expression was determined by ELISA (A) and expression of il17A and il17F were determined using qRT-PCR analysis.

Figure 7. RWE affects key regulator protein of Th17 differentiation. A) $CD4^+$ T cells isolated from draining lymph nodes or mouse spleen from C57bl/6 mice and then they were differentiated into Th17 cells in the presence of anti-CD3 and anti-CD28 for 24h in presence or not of 0.2, 2, 20 and 100 µg/ml of RWE. Expression of p-STAT3, STAT3 and RORγt in naïve T cell and differentiated Th17 cells were assessed by western blotting. B-actin was used as loading control. One representative of three independent experiments. B) Densitometry quantification of western blotting obtained in A). Data are expressed as fold induction of one representative experiment. C) Eight-week old female balb/c mice received of daily oral

administrations of 100 mg/kg/day of RWE or the vehicle during 3 weeks before $CD4^+$ T cells isolated from draining lymph nodes or mouse spleen from C57bl/6 mice nd then they were differentiated into Th17 cells in the presence of anti-CD3 and anti-CD28 for 24h. As in A) Expression of RORγt in naïve T cell and differentiated Th17 cells were assessed by western blotting. B-actin was used as loading control. D) Densitometry quantification of western blotting obtained in C). Data are expressed as fold induction of the average of the 5 mice used in control and treated. Statistical analyses were performed by the Mann-Whitney's test and are shown a significant with $p<0.05$ (*).

Table I. Determination of IC_{50} for RWE on the four colorectal cell lines tested.

Cell lines	IC_{50} of RWE (µg/ml)	
	48h	72h
SW620	123.7 ± 11.9	60 ± 15.7
HCT116	200.0 ± 4.3	74.5 ± 11 .6
MC38	213.5 ± 30.4	200 ± 6.6
CT26	121.0 ± 9.8	150 ±30.0

Figure 1

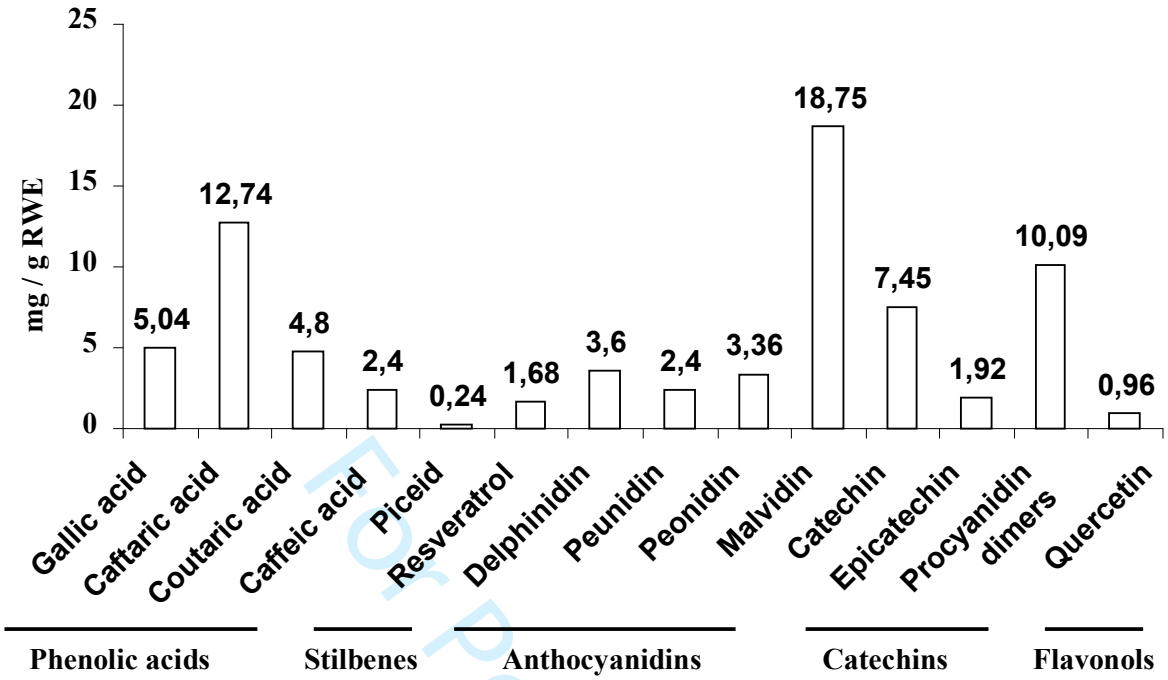


Figure 2

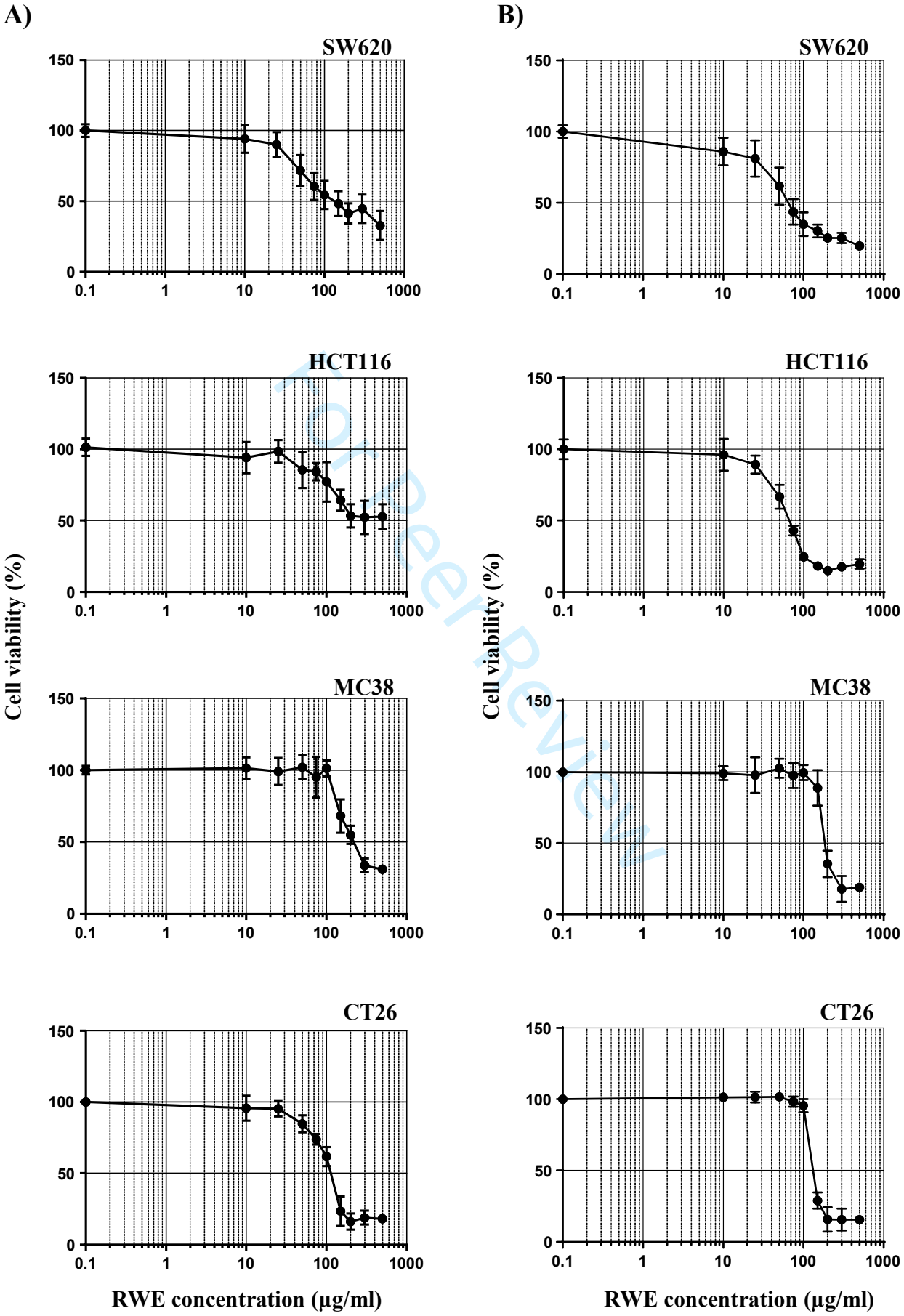


Figure 3

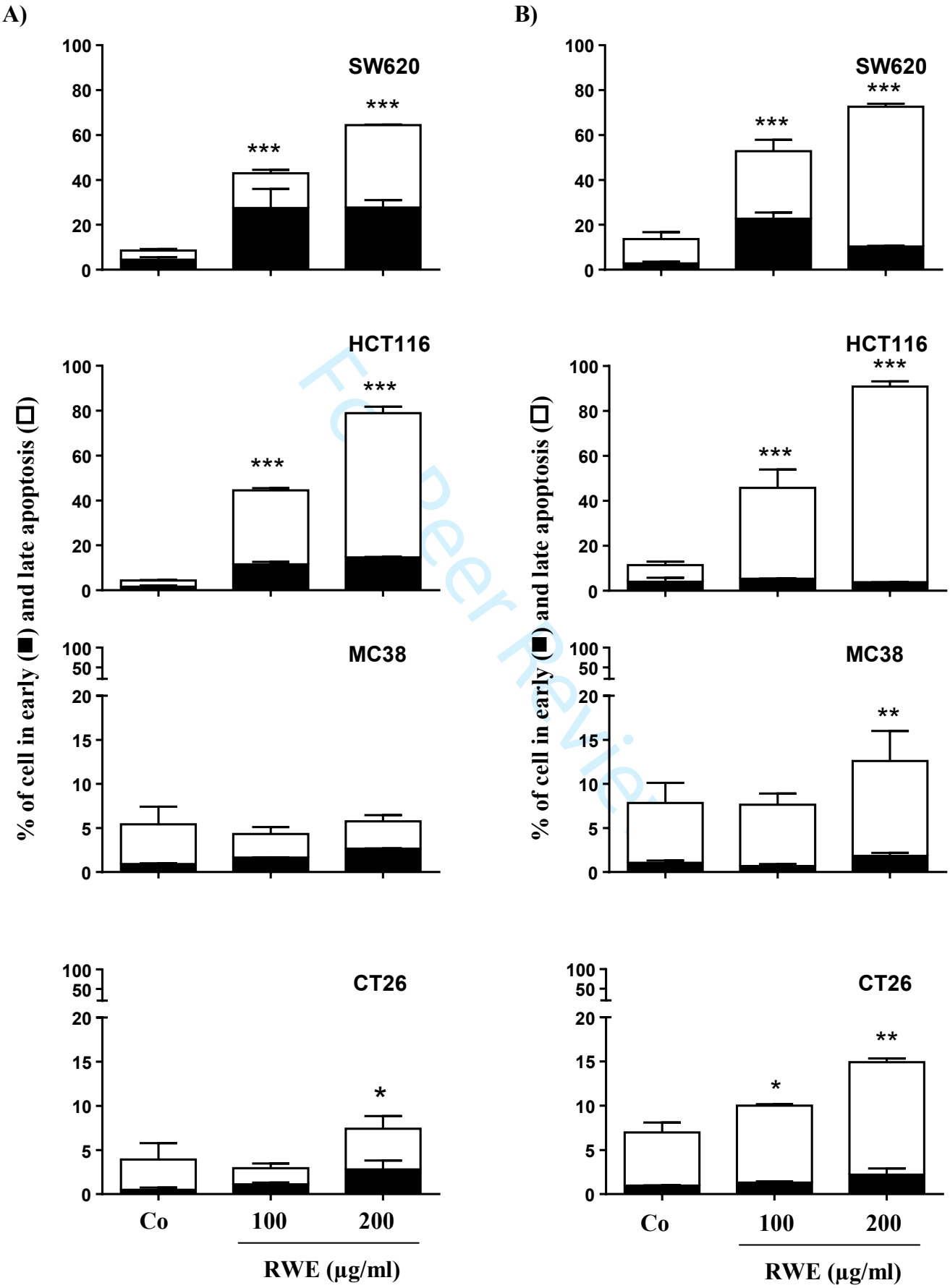


Figure 4

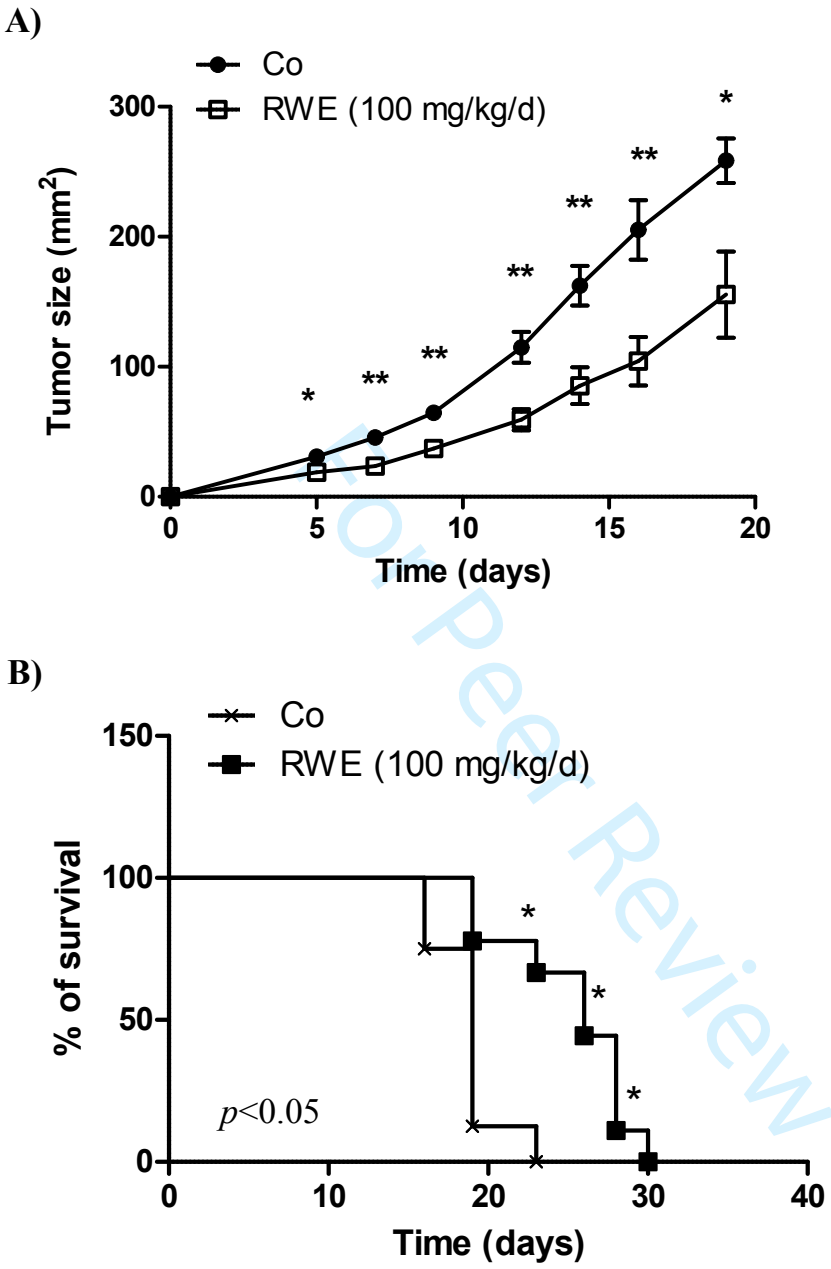


Figure 5

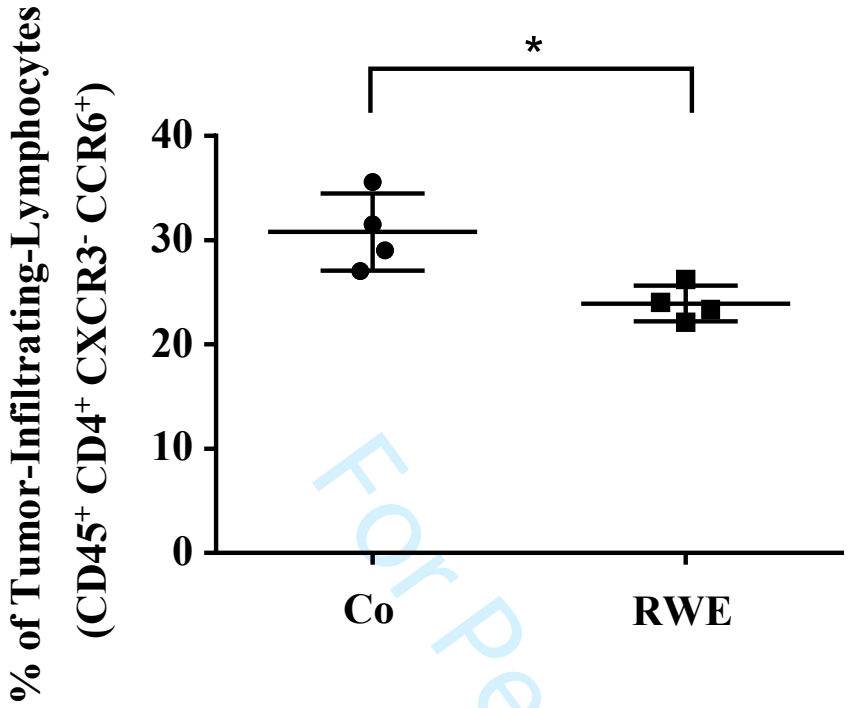


Figure 6

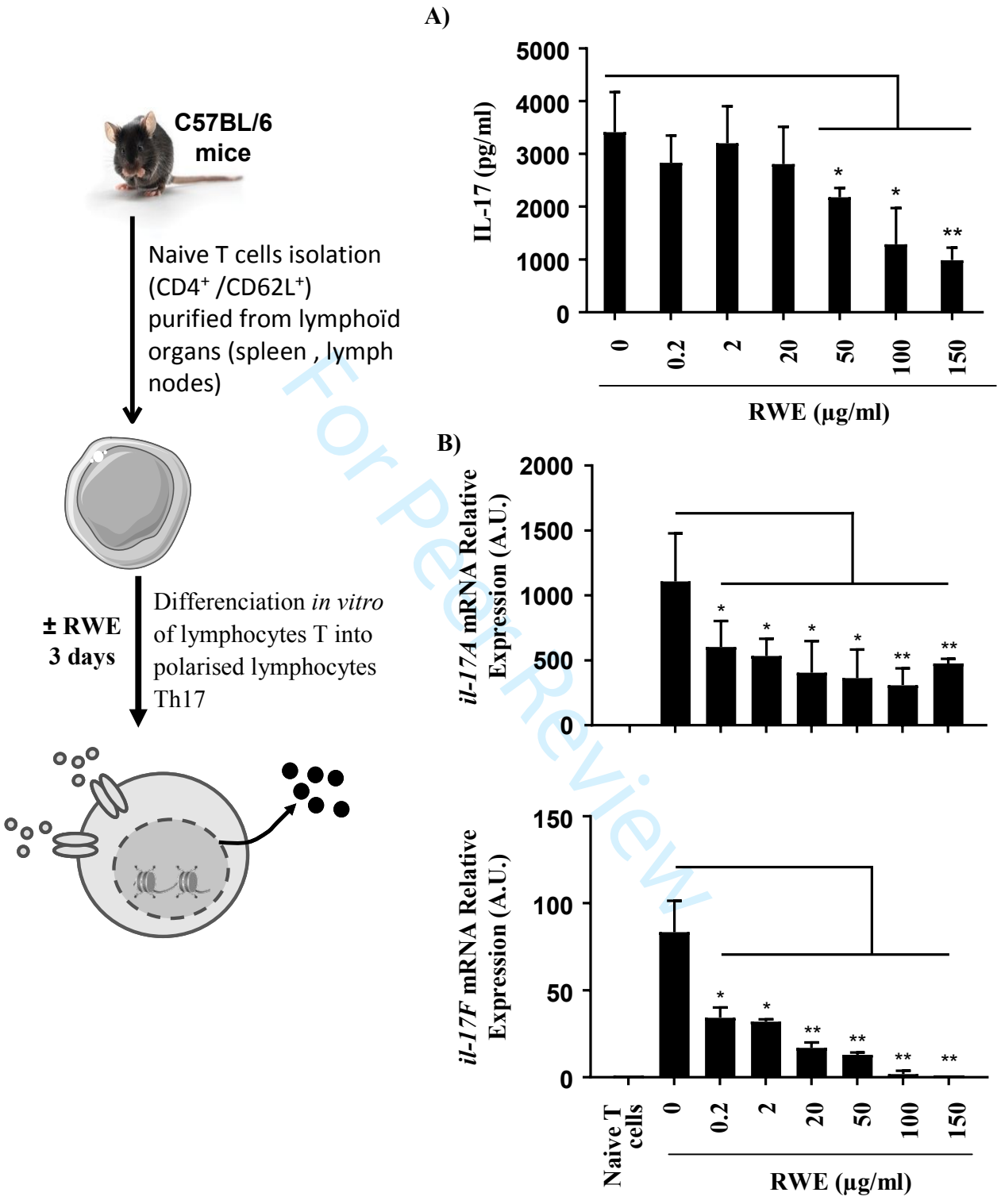
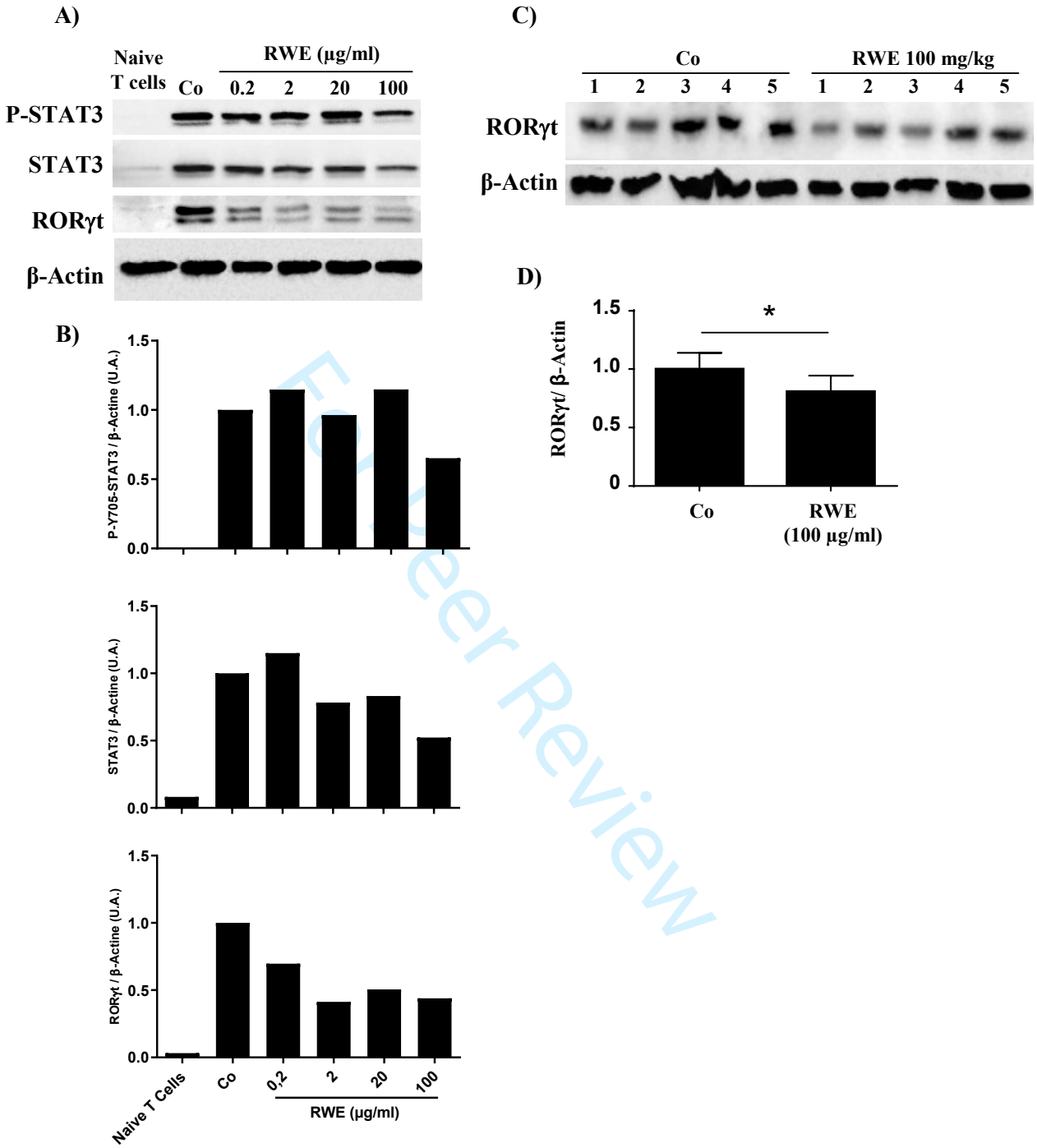
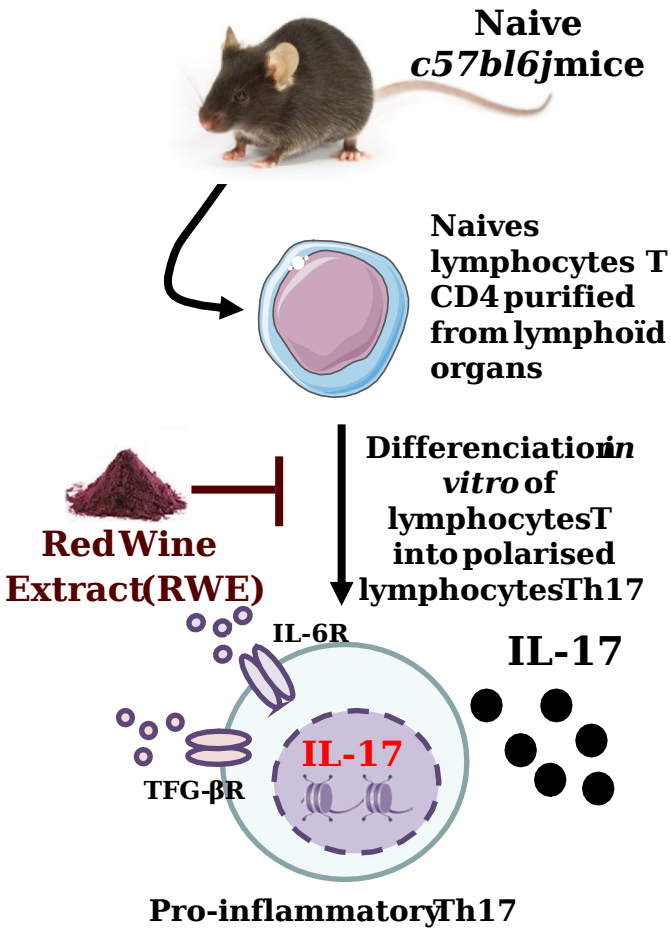


Figure 7




Naive
c57bl6j mice
Naives lymphocytes T CD4 purified from lymphoïd organs
Differenciation in vitro of lymphocytes T into polarised lymphocytes Th17
Red Wine Extract (RWE)
IL-6R
IL-17
IL-17
TFG-βR
Pro-inflammatory Th17

Red Wine extract was able to alter differentiation of lymphocyte T cells into pro-inflammatory Th17 through an alteration of nuclear transcriptional factor, the protein RORγt. Subsequently, Red Wine Extract disrupts pro-inflammatory interleukin IL-17. These events are associated in vivo with a decrease of tumor-infiltrating lymphocytes and with a reduction of colorectal tumor growth.