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## Comparative study on gene expression profile in rat lung after repeated exposure to diesel and biodiesel exhausts upstream and downstream of a particle filter

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## Manuscript Details

**Manuscript number Title** ENVPOL\_2020\_2800\_R1  
Comparative study on gene expression profile in rat lung after repeated exposure to diesel and biodiesel exhausts upstream and downstream of a particle filter

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### Abstract

Biodiesel is considered as a valuable and less toxic alternative to diesel. However, cellular and molecular effects of repeated exposure to biodiesel emissions from a recent engine equipped with a diesel particle filter (DPF) remain to be characterized. To gain insights about this point, the lung transcriptional signatures were analyzed for rats (n=6 per group) exposed to filtered air, 30% rapeseed biodiesel (B30) blend or reference diesel (RF0), upstream and downstream a DPF, for 3 weeks (3h/day, 5 days/week). Genomic analysis revealed a modest regulation of gene expression level (lower than a 2-fold) by both fuels and a higher number of genes regulated downstream the DPF than upstream, in response to either RF0 or to B30 exhaust emissions. The presence of DPF was found to notably impact the lung gene signature of rats exposed to B30. The number of genes regulated in common by both fuels was low, which is likely due to differences in concentrations of regulated pollutants in exhausts, notably for compound organic volatiles, polycyclic aromatic hydrocarbons, NO or NOx. Nevertheless, we have identified some pathways that were activated for both exhaust emissions, such as integrin-, IGF-1- and Rac-signaling pathways, likely reflecting the effects of gas phase products. By contrast, some canonical pathways relative to "oxidative phosphorylation" and "mitochondrial dysfunction" appear as specific to B30 exhaust emission; the repression of transcripts of mitochondrial respiratory chain in lung of rats exposed to B30 downstream of DPF supports the perturbation of mitochondria function. This study done with a recent diesel engine (compliant with the European IV emission standard) and commercially-available fuels reveals that the diesel blend composition and the presence of an after treatment system may modify lung gene signature of rats repeatedly exposed to exhaust emissions, however in a rather modest manner.

**Keywords** Biodiesel; diesel exhaust; lung; particle filter; transcriptome analysis

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**Suggested reviewers** ian gilmour, Miroslav Machala, Lisa Selley, Oddva Myhre, Thais Mauad

## Submission Files Included in this PDF

### File Name [File Type]

ENVPOL\_cover letter.docx [Cover Letter]

Responses to reviewers\_ENVPOL\_2020\_2800.docx [Response to Reviewers]

Lecureur\_Highlights.21.04.20.docx [Highlights]

ENVPOL\_2020\_2800\_Lecureur\_Graphical abstract.pdf [Graphical Abstract]

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ENVPOL\_Lecureur\_Supp data.pdf [Supplementary Material]

## Submission Files Not Included in this PDF

### File Name [File Type]

ENVPOL\_Table S3.xlsx [Supplementary Material]

ENVPOL\_Table S4.xlsx [Supplementary Material]

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Accepted manuscript

Dear Editor,

Please find here attached the revised version of our manuscript (ENVPOL\_2020\_2800) entitled "Comparative study on gene expression profile in rat lung after repeated exposure to diesel and biodiesel exhausts upstream and downstream of a particle filter" by Lecureur et al.

Thank you for the opportunity to address the reviewers' concerns. Please find attached our revised manuscript for consideration of publication in *Environmental Pollution*. We have addressed every issue highlighted by the reviewers. We have also totally reshaped the abstract.

The specific answers to reviewers are attached.

Once again, thank you for considering our revised manuscript,

Yours sincerely,

Valérie Lecureur,

Corresponding author for Ms. ENVPOL\_2020\_2800

## Responses to Reviewer 1:

We thank the reviewer for his supportive comments and helpful suggestions. We have included here our responses:

**1. According to data from Table 1, these results present heterogeneity (e.g. for PAHs in RFO: P1 measure 1 = 1.02 and P1 measure 2 = 9.89). What was the reason of this heterogeneity ?**

As we indicated in the first version of the manuscript, we observed “heterogeneity of PAH concentrations”. Such heterogeneity concerns essentially the measure of naphthalene, the most represented PAHs that we find especially low in the first measure of the RFO campaign; it is not easy to explain these differences in naphthalene concentrations between measures. In the reviewed version, we now added the following sentence: “In fact, a reduced concentration was observed for PAHs except for naphthalene which represents more than 80% of the measured PAHs. The heterogeneity of the PAH concentration upstream DPF may be due to a lower concentration of naphthalene during the first campaign measure, which remains to explain. (Page 7, lines 206-209).

**2. “According to data from table 1, BTEX, aldehyde, alkane and PAHs concentrations were strongly reduced in exhausts downstream of DPF (P2) for B30 fuel, as compared with corresponding concentrations in exhausts downstream of DPF (P2) for RFO fuel. However, the number of genes regulated by B30 fuel after DPF (781 genes) was 1.8 fold higher than that regulated by RFO fuel (426 genes). The authors should explain/discuss this issue”.**

It is true that the number of differentially regulated genes is higher in lung of rats exposed to B30 than those exposed to standard diesel RFO (in P2) (781 versus 426 genes) whereas aldehydes, alkanes and PAHs concentrations were found lower in B30 exhaust than RFO exhaust. However, BTEX, NO and NO<sub>x</sub> concentrations were found higher in B30 than in RFO exhausts downstream DPF (See new data in the Table S1) and such differences may at least in part explain this higher number of genes differentially regulated by B30 exhausts. In the revised manuscript, we now added the following sentence: “So, the greater number of regulated genes in lung of rat exposed to B30 compared to those exposed to RFO may be related at least in part to the higher concentration of fluoranthene, pyrene, NO, NO<sub>x</sub> and VOCs such as BTEX, especially of xylene.” (page 15, lines 445-448).

**3. “According to data from table 1, BTEX, aldehyde, alkane and PAHs concentrations were strongly reduced in exhausts downstream of DPF (P2) for B30 fuel. However, the number of genes regulated by B30 in P2 (downstream DPF) was 5.1 fold higher than in P1 (upstream DPF) (781 versus 153 genes). The authors should explain/discuss this issue”.**

It is true that the number of differentially regulated genes is higher downstream DPF (in P2) than upstream (in P1) (781 versus 153 genes) whereas whole diesel exhaust in P1 contains particles and thus represents a more complex mixture than those in P2, limited to gas phase. The same observation was also done when rats were exposed to RFO emissions. Such data were surprising because we have previously observed in a transcriptomic analysis done on heart tissue of the same rats exposed to diesel emissions that the number of genes was lower downstream DPF (Karoui et al, 2019). In the revised manuscript, we added the following sentence: “However, despite such decreases of exhaust concentrations, the number of regulated genes by B30 emissions was higher downstream than upstream the DPF. Such data were rather surprising since an opposite situation was previously observed in cardiac tissue of rats exposed to diesel emissions (Karoui et al, 2019), suggesting some specific tissue response to gas phase of exhaust or to remaining ultrafine PM.” (Page 13, 401-405).

**“The authors reported that aldehyde concentrations (mostly formaldehyde and acetaldehyde) were highly increased after DPF (P2) for RFO, but were decreased for B30 blend. The authors should explain/discuss this issue”.**

It will be interesting to know why aldehyde and especially acetaldehyde and formaldehyde contents increase in RFO-P2, whereas they decrease in B30-P2/ However, this was not the primary purpose of this study and we can only describe these results, which could explain at least in part the difference in the effects of both fuel exhausts observed in P2, without particles. In accordance with the literature, B30 generates slightly less total aldehyde emission than diesel does. Moreover, when oxidation reaction occurs in catalyst, the intermediate products such as formaldehyde are formed. It is possible that less formaldehyde in B30 emissions was produced because of the 30% dilution of exhaust. In the revised manuscript, we added the following sentence: “As formaldehyde may be an intermediate product from other aldehydes or hydrocarbons during oxidation reaction in catalyst, its decrease in exhausts from B30 in comparison to those of RFO may be related to the 30% dilution of diesel and thus to the lowest concentration of such initial compounds in B30 blend.” (page 13, lines 395-400).

#### Responses to Reviewer 2:

We thank the reviewer for his supportive comments and helpful suggestions. We have included here our responses:

**1. “The abstract is quite confusing and it would be best if the authors first described what transcription pathways are induced by the whole exhaust fuels compared to the air controls and then highlight differences or new pathways attributed to the filtered emissions. The concentration of exhaust that the animals were exposed to for each fuel would be good to include in the abstract”.**

As suggested by reviewer 2 and 4, we reshaped the abstract.

However, we did not first described what transcription pathways are induced by the whole exhaust fuels compared to the air controls and then highlight differences or new pathways attributed to the filtered emissions, because our data were essentially focused on B30 exhausts and because we did not compared the transcription pathways downstream and upstream the DPF for RFO.

In this new abstract, we also gave now some informations concerning methods and exposure procedure. In addition, as suggested by the Reviewer 4, we now better overall summarize the results.

**2. “At the end of the discussion the Douki et al paper is introduced as being part of this overall program and perhaps has broader effects that this genomic analysis is trying to explain. It would be good to summarize this paper in the introduction as a launch point for this current study.”**

As suggested by the Reviewer, we now introduce Douki et al article with the other one (Karoui et al, 2019) from our research consortium in the Introduction section. In the revised manuscript (Page 4, lines 95-99), we have thus indicated: “Concerning our studies, we evaluated the global genomic effects of repeated exposure to diesel exhaust on rat heart and identified some pathways related to mitochondrial dysfunction (Karoui et al, 2019). In lung tissue of rats exposed to diesel and biodiesel exhausts, no significant alteration of pathways related to genotoxicity was additionally observed (Douki et al, 2018).

**3. “The schematic of the exposure system and experimental design does not include air controls and that would be more complete so that people understand this was a balanced experimental design”.**

We thank the Reviewer for this comment. We now add on the graphical abstract the exposure to air (as control).

**4. “The abstract says that the exposures caused “modest adverse effects”. What exactly are these “adverse effects”. I see some changes in genomic expression but don’t know if they are adverse”.**

It is true that the transcriptomic analysis alone cannot permit to know if the effects of exposure to diesel exhaust can cause adverse effects. That is why, and under the recommendation of one of the reviewers, we

now added new data based on histological analyses in the revised version of this article. In the Figure S2, we showed the histological scores of lung inflammation, (that we can consider as adverse effects), which appear slightly higher in B30-exposed rats than in RFO-exposed rats both upstream and downstream of DPF. Such data are now presented in the results section (page 8) and discussed page 13.

**5. .... Also there is no data on the levels of accompanying gases (Nox, CO etc.) This may be previously published but the readership would be interested in a standard summary table of this.**

In fact, some of these data were previously published in Douki et al. (2018). As requested, we added data on regulated gaseous pollutants concentrations such as NO, NO<sub>x</sub>, CO and total gaseous hydrocarbons in a supplementary table (Table S1) and we now mention some details concerning operating conditions (NEDC cycle). The following new paragraph appears now in the revised version of the article: “The exhaust characterization was performed upstream (P1) and downstream (P2) of the DPF during the NEDC cycles. The results showed that DPF reduced the total PM concentrations for both fuels (Table S1). NO and NO<sub>x</sub> concentrations were found higher in B30 than RFO exhausts, in contrast to CO concentrations, and the presence of DPF did not change the total gaseous hydrocarbon concentrations (Table S1).” (Page 7, lines 194-

**6. “The figure legends do not say how many animals for each group were subjected to the genomic analysis. I assume it was all 6 but it is not clear.”**

As recommended by the Reviewer, we now added the number of rats in each group on the Figure 1. The number of rat lung tissues used for genomic analysis was precise at Page 6, line 165: “Raw affimetrix data (.CEL files) from 36 arrays (corresponding to six lung samples from two campaign of exposure to RFO and B30 with 6 rats/group)...”

**7. “This analysis was performed on a small piece of lung (which comprises 40 different cell types). The origin of the genomic changes (whether this is resident cells or perhaps new cells) should be discussed.”**

We thanks the Reviewer for this pertinent suggestion. In fact, the genomic changes may be related to the response of resident but also to the recruited cells in the lung tissue. We therefore propose the following sentence: “Because of such mild lung inflammation, we cannot argue that the genomic signatures reflect only the molecular changes within lung resident cell population, but also probably those of infiltrated cells.” (page 13, lines 385-387).

**8. “Were mass measurements done after the filter to ensure the filter actually worked and to what extent? “**

As suggested by the Reviewer, we now added the data on PM mass measurement in a supplementary table (Table S1). These data are now included in the text as followed: “The results showed that DPF reduced the total PM concentrations both for both fuels (Table S1)” (Page 7, lines 195-196) and “The efficiency of the DPF was confirmed by the near absence of PM downstream the DPF” (Page 13, line 388).

**9. “Terming the filter a “depollution device is a little strange.”**

We have changed device by system

**10. “The Finch et al paper if I recall did not study genomic responses to biodiesel and therefore the statement on page 7 line 92 is misleading.**

We agree with the Reviewer that in Finch et al article, which was one of the first to study a subchronic exposure of rats to emission from a diesel engine burning soybean for a long period (13 weeks), no genomic study was done. Therefore, we removed this reference from the paragraph concerning transcriptomic approaches in the introduction.

**11. “The Stevens et al paper that was cited also described genomic pathway analyses for several types of diesel samples and parallels where appropriate between the current study and earlier work would be informative.”**

We now discuss about Stevens et al data in the text as followed: “Also, the identification of the “oxidative phosphorylation” pathway in mice exposed to diesel exhaust (Stevens et al., 2008) .....” (Page 14, lines 429-430).

### Responses to Reviewer 3:

We thank the Reviewer for his supportive comments and helpful suggestions. We have included here our responses:

**1. “Details of engine operation are necessary to be included. Is the engine operating with or without load?. If it was under a load, what is the operational cycle? Such aspects are important, since the operation mode of the engine may alter the emission composition”**

We thank the Reviewer for this comment. As the exposure procedure was already published in the Douki et al, article, we limited the detail of engine operation in this article. But, as requested, we now add these information in the text: “The diesel engine was placed in a test bench cell equipped with a dynamic asynchronous chassis dyno, which allows continuous control of both engine speed and load, and was used under dynamic conditions according to the “New European Driving Cycle” (NEDC).” (page 4 , lines 111-113).

**2. “Authors fully acknowledge that some integrative toxicologic endpoint, such as cell counts obtained by bronchoalveolar lavage, could be of use. However, they had lung tissue material. Did they measured quantitative markers of pulmonary alteration, such as phenotypic changes of airways (lowe and upper), including mucin profile secretion or tissular accumulation of inflammatory cells? Do they have samples of blood, bone marrow or other organs? Although I fully acknowledge that the emphasys of the study was on the different gene expression profiles, perhaps these additional pieces of information could provide a supportive background for the comparative toxicity of both fuels”**

We thank the Reviewer for these comments. We do not have no more lung tissue to realize new measurements such as mucin profile secretion for example. We have previously counted blood samples and as already indicated in the manuscript, we did not see any difference between groups of rats (page 8, lines 231-232). It is true that we have some tissue samples from others tissues (heart, liver and kidney); the analysis of diesel exhaust on heart tissue has been the subject of a publication (Karoui et al, 2019) but the analysis of other tissue samples was not done yet and is not the subject of this article.

As suggested by the Reviewer, we now presented some lung histological data such as histological score of lung inflammation and some lung tissue section showing alveolar macrophages in the Figure S2.

These data are now presented in the text as followed: “Histopathological examinations did not show major structural lung tissue alteration. It however revealed the presence of pigmented macrophages in the alveolar space of rats exposed to exhausts in P1, but not in the group of rats exposed to filtered air nor in the group of rats exposed to both fuels downstream the DPF (Figure S2). The histological scores of lung inflammation showed no or a mild inflammation in the lung of rats exposed to filtered air; they were higher in B30-exposed rats than those of rats exposed to Rf0 both downstream the DPF (100% of mild-moderate inflammation versus 44%) and upstream the DPF (83% of mild-moderate inflammation versus 67%) (Figure S2).” (Page 8, lines 232-240) and in the discussion section of the article Page 13, lines 381-387.

**3. “Finally, I think that conclusions should be somehow made more simple, since the general reader of Environmental Pollution may be not used to the jargon of molecular toxicology.”**

As suggested by the Reviewer, we re-worded the conclusion to simplify it; see page 16, lines 481-485.



## Responses to Reviewer 4:

We thank the Reviewer for his supportive comments and helpful suggestions. We have included here our responses:

**1. Abstract: a better overall summary of the results should be provided**

As suggested by Reviewer 2 and Reviewer 4, we reshaped the abstract. In this revised abstract, we also give now some information concerning methods and exposure procedure. And, as suggested by the reviewer4, we now better overall summarize the results.

**2. Results, section 3.2 - more appropriate title should be used.**

We have changed the title of this section and replace "Measurement of different parameters in animals" by "Analysis of tissue and of biological parameters".

**3. Results, section 3.2, line 212 - the weight changes between the groups are not significant (except of an RF0/P1 vs. controls comparison). This should be clearly indicated in the text.**

We have changed the previous sentence : "Overall, the weight-gain of rats exposed to fuels was lower than those exposed to air, but rats exposed to RF0 before DPF (P1) showed a significant reduction in weight-gain when compared to their respective filtered air controls" by a new sentence : "Overall, there were no weight change between groups, except in the group of rats exposed to RF0 before DPF (P1), which showed a significant reduction in weight-gain when compared to their respective filtered air controls (Table S2)." (Page 8, lines 229-231).

**4. Results, section 3.3 - correct a typo "Genes differentially expressed..."**

The "Gene differentially expressed..." was replaced by "Genesdifferentially expressed"

**5. "Results, section 3.4, line 306 - "oxidative phosphorylation"**

"oxydative phosphorylation" was changed for "oxidative phosphorylation".

**6. "Discussion, line 354 (point 3) - it is not clear for which groups the comparison is being made"**

Thanks for this comment. To avoid confusion, we removed the previous sentence: "The same procedure was applied to the canonical pathways found for B30-exposed rats in P1 but no z-score was attributed to them." to only present data where z-score were attributed to pathways, i.e. B30-P2 (Page 12, lines 353-354).

**7. "Table 1 - big differences between measurements 1 and 2 for some compounds were found (e.g. BTEX, B30). Some explanation should be provided."**

We thank the Reviewer for its comment, which was also pointed out by the first reviewer. It is true that we found some heterogeneity between the 2 measurements done for each exposure campaign. Concerning BTEX measurement, we found an higher concentration of xylene in the second measurement in comparison to the first which explain the highest value of BTEX in emissions of B30 upstream the DPF. This detail is now precise in the text as followed:"The heterogeneity in BTEX concentrations measured in B30 emissions upstream the DFP was due to a highest xylene concentration in the second measure than the first." (Page 8, lines 217-218).

**8. The authors should discuss the reasons for more pronounced response after P2 exposures, particularly for B30.**

We thank the Reviewer for its comment, which was also pointed out by the first reviewer.

Please find here our responses for both reviewers : It is true that the number of differentially regulated genes is higher in lung of rats exposed to B30 than those exposed to standard diesel RFO (in P2) (781 versus 426 genes) whereas aldehydes, alcanes and PAHs concentrations were found lower in B30 exhaust than RFO exhaust. However, BTEX, NO and NOx concentrations (new data in the Table S1) were found higher in B30 than in RFO exhausts downstream DPF and such differences may at least in part explain these higher number of genes differentially regulated by B30 exhausts.

In the revised manuscript, we now added the following sentence: "So, the greater number of regulated genes in lung of rat exposed to B30 compared to those exposed to RFO may be related at least in part to the higher concentrations of fluoranthene, pyrene, NO, Nox and VOCs such as BTEX, especially of xylene." (page 15, lines 445-448).

**9. For gene expression analysis, microarray technology was used, although NGS provides more comprehensive results. The authors should explain why they used this approach and mention it in the study limitations.**

When we started this collaborative project, the next-generation sequencing was not so widespread and anyone in the consortium team wasn't familiar with this technology. I think that if we would start this type of study in 2020, we will used NGS. Therefore, we propose the following sentence in the "limitations" paragraph: "Second, this transcriptomic study could have been carried with a more recent and more efficient approaches, such as the next-generation sequencing (NGS), but when this study began, NGS was quite expensive and not so spread." (Page 16, lines 472-474).

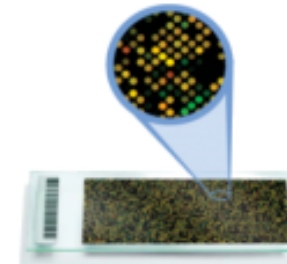
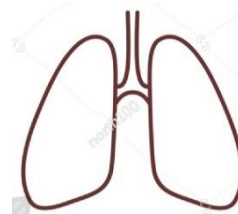
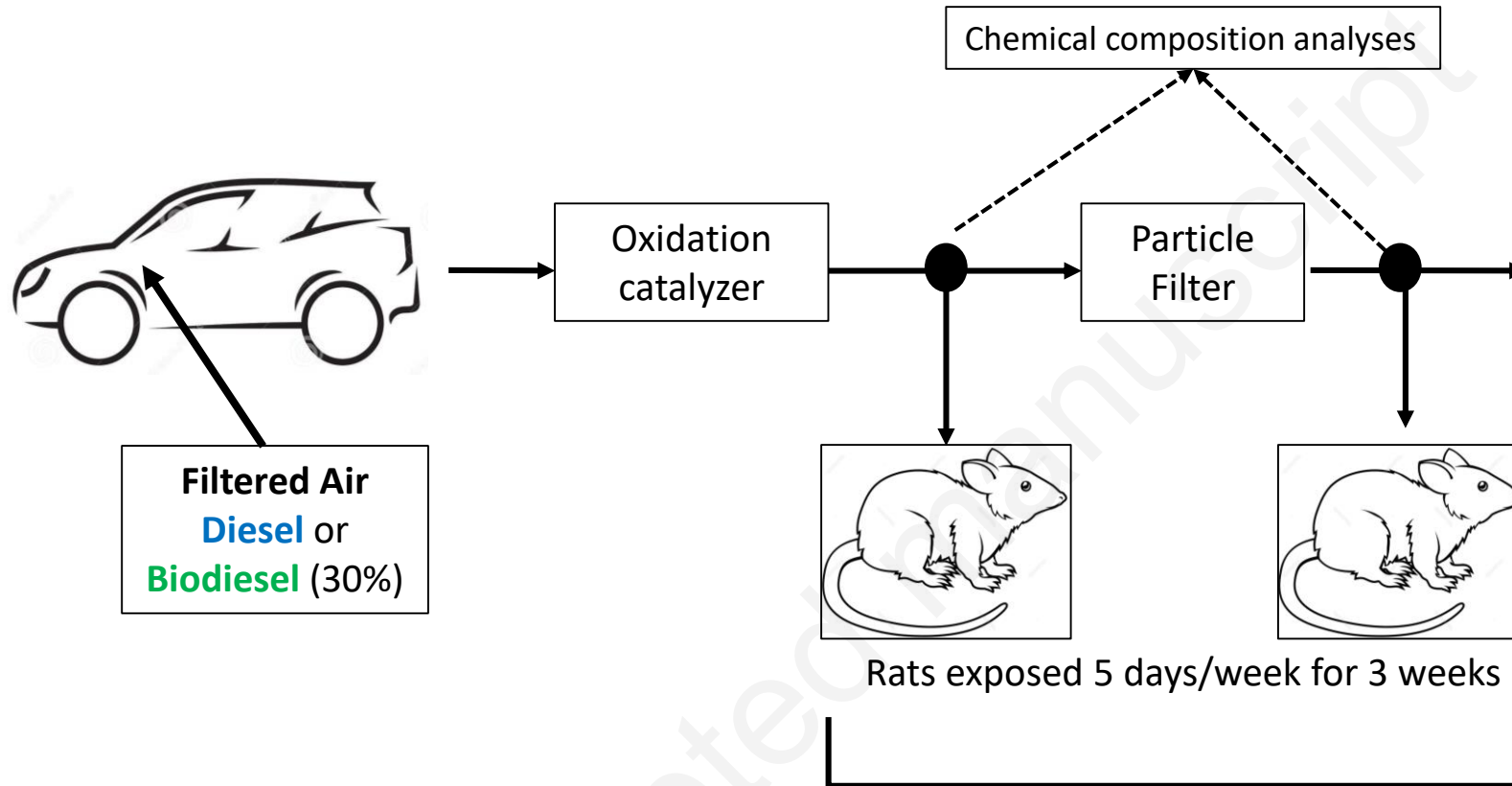
**10. How do the exposure doses compare to real-life exposure scenarios?**

Some comments on the realistic exposure were previously published in the article of Douki et al, 2019. But as suggested by the Reviewer, we decided to add some sentences concerning the real-life scenario of exposure in this article in the Materials and Methods part. Therefore, we now added the following sentence: "This design of exposure is representative of a realistic exposure because the dose was based on the quantile 75% value of the concentrations found inside a car in an urban traffic (Morin et al, 2009). And the daily 3 h exposure corresponds to a high but plausible exposure duration, to which people may be exposed on their 5 working days" (Page 5, lines 136-140).

**Highlights:**

- Repeated lung exposures to diesel or biodiesel induce low level expression of genes
- Exposure to diesel or biodiesel induces a different profile of gene expression
- Diesel particle filter modifies exhaust composition and gene expression profile
- Mitochondrial dysfunction is observed downstream the diesel particle filter

Accepted manuscript



Comparative studies of lung gene expression profiles

1 **Comparative study on gene expression profile in rat lung after repeated exposure to diesel**  
2 **and biodiesel exhausts upstream and downstream of a particle filter**

3

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24

25 **Abstract**

26 Biodiesel is considered as a valuable and less toxic alternative to diesel. However, cellular and  
27 molecular effects of repeated exposure to biodiesel emissions from a recent engine equipped  
28 with a diesel particle filter (DPF) remain to be characterized. To gain insights about this point,  
29 the lung transcriptional signatures were analyzed for rats (n=6 per group) exposed to filtered  
30 air, 30% rapeseed biodiesel (B30) blend or reference diesel (RF0), upstream and downstream  
31 a DPF, for 3 weeks (3h/day, 5 days/week).

32 Genomic analysis revealed a modest regulation of gene expression level (lower than a 2-fold)  
33 by both fuels and a higher number of genes regulated downstream the DPF than upstream, in  
34 response to either RF0 or to B30 exhaust emissions. The presence of DPF was found to notably  
35 impact the lung gene signature of rats exposed to B30. The number of genes regulated in  
36 common by both fuels was low, which is likely due to differences in concentrations of  
37 regulated pollutants in exhausts, notably for compound organic volatiles, polycyclic aromatic  
38 hydrocarbons, NO or NOx. Nevertheless, we have identified some pathways that were  
39 activated for both exhaust emissions, such as integrin-, IGF-1- and Rac-signaling pathways,  
40 likely reflecting the effects of gas phase products. By contrast, some canonical pathways  
41 relative to "oxidative phosphorylation" and "mitochondrial dysfunction" appear as specific to  
42 B30 exhaust emission; the repression of transcripts of mitochondrial respiratory chain in lung  
43 of rats exposed to B30 downstream of DPF supports the perturbation of mitochondria  
44 function.

45 This study done with a recent diesel engine (compliant with the European IV emission  
46 standard) and commercially-available fuels reveals that the diesel blend composition and the  
47 presence of an after treatment system may modify lung gene signature of rats repeatedly  
48 exposed to exhaust emissions, however in a rather modest manner.

49  
50 **Keywords:** Biodiesel; diesel exhaust; lung; particle filter; transcriptome analysis

51 **Capsule:** The lung gene signatures of rat exposed repeatedly to diesel and biodiesel vary with  
52 the diesel composition, the presence of a diesel particle filter and support modest lung  
53 adverse effects.

54

## 55 **1. Introduction**

56 According to global burden of diseases, ambient particulate matter (PM) pollution is the  
57 first environmental or occupational risk of deaths (Cohen et al., 2017). It causes an estimated  
58 5.25% of all deaths and is the eighth-ranking global mortality risk factor in 2017 (GBD 2016  
59 Risk Factors Collaborators, 2017). Increased mortality and morbidity related to ambient PM  
60 exposure is notably related to cardio-pulmonary diseases (Cohen et al., 2017; Miller et al.,  
61 2012; Pope et al., 2002). Road traffic, which is the third major source of the airborne particles  
62 (EEA Report 2019), and exposure to diesel exhaust particle (DEP), including fine particles such  
63 as PM<sub>2.5</sub>, contribute to lung adverse effects, notably to exacerbations of asthma and to  
64 allergic airway diseases (Ghio et al., 2012; Steiner et al., 2016).

65 The diesel emissions of vehicles contain numerous chemical compounds, which are emitted  
66 in both the gaseous and particulate phases of the exhaust resulting from an incomplete  
67 combustion of diesel fuel. The main components of diesel exhausts comprise carbon  
68 monoxide and dioxide, nitrogen and sulphur oxides, volatile polycyclic aromatic hydrocarbons  
69 (PAHs) and PM ranging from fine (2.5-0.1  $\mu\text{m}$  diameter) to ultrafine (<0.1  $\mu\text{m}$  diameter),  
70 known to reach the deep airways. Toxic effects of these DEPs are related to their capacity to  
71 interact with alveolar macrophages and lung epithelial cells, triggering inflammation,  
72 oxidative stress and immune response (Ristovski et al., 2012), or to their direct translocation  
73 into the circulation (Nemmar et al., 2002, 2001).

74 Trans-esterified lipids of soybean and rapeseed oils have a potential for use in energy  
75 combustion. They represent alternative fuels when they are mixed at levels of 20-30% with  
76 standard diesel fuel, leading to some difference between biodiesel- and diesel-emissions  
77 (Bünger et al., 2012). The increased use of these biofuels, which accounted for about 7 percent  
78 of the energy use in transport in 2018 in Europe (EU Biofuels Annual 2019), may change  
79 atmospheric pollution profile. This potentially causes different health effects. Some  
80 depollution systems such as diesel particulate filter (DPF) installed on all new vehicles in  
81 European Union (since the European emission standard Euro V), permit to reduce particle  
82 emission. However, to date, knowledge concerning the toxicological effects of the biodiesel  
83 emissions from recent engine in the presence of depollution system is still insufficient (Godri  
84 Pollitt et al., 2019; Weitekamp et al., 2020).

85 Recently, “omics” approaches have been applied extensively in the field of toxicology to  
86 identify new biomarkers and to unravel molecular mechanisms of toxicity. Transcriptomic

87 studies based on microarray analysis to assess biological risks of diesel exhaust exposure were  
88 usually realized after an acute exposure to exhausts (Pettit et al., 2012; Srivastava et al., 2014;  
89 Stevens et al., 2008; Yanagisawa et al., 2004), and more rarely after a probably more relevant  
90 sub-chronic exposure (Maresh et al., 2011). A recent review pointed out the interest of 91  
“omics” for investigating biodiesel-induced pulmonary toxicity (Selley et al., 2019). Indeed, 92  
few studies have analyzed the genomic response of rodents exposed repeatedly to 93 diesel/  
biodiesel exhausts, except those from the “FuelHealth project” and from our research 94  
consortium. The authors of the “FuelHealth project” analyzed the genomic impact of a 28- 95  
days inhaled diesel and biodiesel exhaust exposure on rat brain and lung tissues, but with 96  
however only a limited number (32) of analyzed interest genes. Concerning our studies, we 97  
evaluated the global genomic effects of repeated exposure to diesel exhaust in rat heart and 98  
identified some targeted pathways related to mitochondrial dysfunction (Karoui et al, 2019). 99  
In lung tissue of rats exposed to diesel and biodiesel exhausts, no significant alteration of  
100 pathways related to genotoxicity was additionally observed (Douki et al, 2018).

101 The present study is a part of our consortium research project concerning diesel/biodiesel  
102 exhaust effects and was designed to determine and compare the alterations of gene 103  
expression in lung of rats exposed repeatedly to 30% rapeseed biofuel (B30) or reference 104  
diesel (RF0), upstream and downstream of a DPF depollution system, through performing a 105  
pan-genomic microarrays-based transcriptomic analysis.

106

## 107 **2. Materials and Methods**

### 108 *2.1. Exhaust generation and monitoring of emissions*

109 Diesel emission was produced by a light duty four cylinder direct-injection engine equipped  
110 with an oxidation catalyst, with or without a wall-through DPF, as previously described  
(Douki 111 et al., 2018). The diesel engine was placed in a test bench cell equipped with a  
dynamic 112 asynchronous chassis dynamometer, which allows continuous control of both engine speed  
and load; 113 it was used under dynamic conditions according to the “New European Driving  
Cycle” (NEDC). 114 The standard fuel PSA4 (RF0) used was a low content sulfur fuel. It was  
mixed to yield 30% 115 rapeseed methyl ester content (B30). Emissions from an internal  
combustion engine 116 (European Euro IV standard diesel) were drawn directly from the  
exhaust line. The primary 117 dilution by a factor 10 was performed by a Fine particle  
sampler (Dekati Finland). Average



118 concentrations of regulated pollutants in RFO and B30 exhausts during NEDC cycling before  
119 dilution and exposure were previously published (Douki et al., 2018).

120 Emission components were measured from the atmosphere collected upstream the DPF,  
121 which consists in both gaseous and particulate phases, while that collected downstream  
122 contains the gaseous phase. The particulate phases were sampled upstream of the DPF by  
123 using a sampling system consisting in a transfer line heated according to the temperature of  
124 the emitted gases and heated filter. The gases were trapped using various adsorbing cartridges  
125 (e.g., Amberlite XAD-2 resin, multibed carbotrap (Carbosieve III, carbotrapB et C), 2,4-  
126 Dinitrophenylhydrazine) selective for the different types of targeted compounds. The  
127 sampling flow was controlled using mass flowmeters and a pump, as indicated in Fig. S1.

128

## 129 *2.2. Animals housing and exposure*

130 Rat exposure to exhaust has been previously described by our research consortium (Douki  
131 et al., 2018). Briefly, pathogen-free male Wistar rats weighing 270-300 g (Janvier Inc, Le  
132 Genest Saint Isle, France) were randomly divided into 6 groups, each containing 6 animals,  
133 and were placed in inhalation chambers (Anselme et al., 2007). Two exposure experiments  
134 were conducted with fuel exhaust: rats exposed 3 h/day x 5 days per week x 3 weeks to RFO  
135 or B30 were collected either at P1 (upstream DPF) or P2 (downstream DPF) (Fig. S1). In  
parallel, 136 a control group was exposed to filtered air for each exposure campaign. This design  
of 137 exposure is representative of a realistic exposure because (i) the dose was based on the  
138 quantile 75% value of the concentrations found inside a car in an urban traffic (Morin et al,  
139 2009) and (ii) the daily 3 h exposure corresponds to a high but plausible exposure duration  
to 140 which people may be exposed on their 5 working days. About 16 h after the last exposure,  
141 rats were sacrificed, blood samples were collected for cell counting and lungs were removed.  
142 All analyses were performed in a blind manner. Animal studies were reviewed and approved  
143 by the Committee on the Ethics of Animal Experiments under the authority of the French  
144 Ministry of Higher Education and Research (Authorization number 00291.01). They were  
145 carried out in strict accordance with the recommendations found in the Guide for the Care  
146 and Use of Laboratory Animals, EEC Council Directive 2010/63/EU.

147

## 148 *2.3. Lung histology*

149 A piece of lung (left upper lobe) was fixed with 4% formol, embedded in paraffin and  
150 sectioned at a thickness of 3  $\mu$ m on a microtome. Prepared sections were stained with  
151 hematoxylin-eosin-saffron (HES). Histopathological evaluation was performed by a certified  
152 pathologist. Sample identification was coded to ensure unbiased evaluation.

153

#### 154 2.4. Microarray analysis

155 RNA from frozen lung tissue (piece of right lobe) was isolated using RNeasy Plus mini kit  
156 following manufacturer's protocol (Qiagen, Courtaboeuf, France). The RNA quantity and  
157 quality, assessed by a RNA integrity number superior to 9, were evaluated with a Nanodrop  
158 spectrophotometer and the Agilent 2100 Bioanalyser (Agilent technologies, Santa Clara, CA,  
159 USA), respectively. RNA was reverse-transcribed, converted to biotinylated complementary  
160 RNA and hybridized to GeneChip® RAGENE 2.0 ST Arrays, representing the whole rat genome,  
161 at the genomic platform of the Cochin Institute (Paris, France), according to Affimetrix  
162 protocol (Affimetrix, Santa Clara, CA, USA). Microarrays were washed and stained, and  
163 fluorescent images were obtained using the Affymetrix 3000 Scanner. Raw affimetrix data  
164 (.CEL files) from 36 arrays (corresponding to six lung samples from two campaign of exposure  
165 to RFO and B30 with 6 rats/group) were transformed by the Robust Multichip Analysis method,  
166 corresponding to a correction, normalization and summarization of expression values.  
167 Standard quality metrics of Partek® and principle component analysis (PCA) allowed to detect  
168 potential outliers. The Ingenuity Pathway Analysis (IPA) software (Ingenuity Systems,  
169 Mountain View, CA) was used to identify and associate signalling pathways and biological  
170 functions to the experimental transcriptomic results. Networks were "named" on the most  
171 prevalent functional group(s) present, whereas Canonical Pathway (CP) analysis identified  
172 function specific genes significantly present within the networks.

173

#### 174 2.5. Quantitative real-time PCR

175 Total RNAs were reverse-transcribed using the High-Capacity cDNA Reverse Transcription  
176 Kit (Applied Biosystem, Courtaboeuf, France). qPCR assays were next performed using the  
177 fluorescent dye SYBR Green methodology and an ABI 7900 detector (Applied Biosystem). The  
178 KiCqStart® SYBR® Green primers for rat cDNAs were provided by Sigma-Aldrich. The specificity  
179 of amplified genes was evaluated using the comparative cycle threshold method with the ABI  
180 Prism SDS software. The relative gene expression was calculated by using the  $\Delta\Delta C_T$  analysis

181 for each sample, after normalization against  $\beta$ -actin gene expression. The air-exposed rat  
182 served as a reference and their mRNA expression was arbitrarily set as 1 unit.

183

## 184 2.6. Statistical analysis

185 For qPCR analysis, results are expressed as means  $\pm$  sem. Comparison between more than  
186 two groups were performed by one-way analysis of variance followed by Newman-Keuls  
187 multiple comparison post-hoc test. A student's *t* test was used to compare two groups.  
188 Differences were considered statistically significant when  $p < 0.05$ . Data analysis were  
189 performed with GraphPad Prism 5.0 software (GraphPad Software, La Jolla, CA, USA).

190

191

## 192 3. Results

### 193 3.1. Biodiesel and diesel combustion emission analysis

194 The exhaust characterization was performed upstream (P1) and downstream (P2) of the  
195 DPF during the NEDC cycles. The results showed that DPF reduced the total PM concentrations  
196 for both fuels (Table S1). NO and NO<sub>x</sub> concentrations were found higher in B30 than RFO 197  
exhausts, in contrast to CO concentrations, and the presence of DPF did not change the total 198  
gaseous hydrocarbon concentrations (Table S1). Concerning PAHs, particulate PAH 199  
concentrations measured upstream DPF (P1) ranged to 0.1-0.3  $\mu\text{g}/\text{m}^3$  for both fuels. PAHs 200  
concentrations were next measured in the gas phase upstream and downstream of the DPF 201 on  
XAD resin. The major PAHs identified were naphthalene > phenanthrene > fluoranthene 202 and  
pyrene, whereas the measures of other PAHs were under the limit of detection (for 203 example,  
benzo[a]pyrene < 1  $\text{ng}/\text{m}^3$ ). PAH concentration in B30 blend, ranging from 2.3-4.0 204  $\mu\text{g}/\text{m}^3$ , was  
strongly decreased after DPF (P2) (Table 1), whereas such effect was less evident 205 for the RFO  
fuel, likely due to a heterogeneity of PAH concentrations upstream DPF (P1) (Table 206 1). In  
fact, a reduced concentration was observed for PAHs, except for naphthalene which 207  
represents more than 80% of the measured PAHs. The heterogeneity of the PAH 208  
concentration upstream DPF may be due to a lower concentration of naphthalene during the 209  
first campaign measure, which remains to explain. However, it appears that naphthalene 210  
concentration was less important in exhaust from B30 fuel than from RFO fuel, whereas 211  
fluoranthene and pyrene concentrations seemed higher in B30 than in RFO fuels (data not 212  
shown). Alkane (C8-C40) concentrations upstream DPF (P1) were heterogeneous for both

213 fuels, but they clearly decreased after DPF (P2) for B30 but not for RFO fuels (Table 1). The  
214 measure of some volatile organic compound (VOC) (BTEX for benzene, toluene, ethylbenzene  
215 and xylene) showed a higher concentration of these compounds in exhaust from B30 blend  
216 than RFO fuel, as previously described (Beer et al., 2007), but the DPF has been clearly  
efficient 217 to reduce their amount for both fuels (Table 1). The heterogeneity in BTEX  
concentrations 218 measured in B30 emissions upstream the DPF was due to a xylene  
concentration highest in 219 the second measure than in the first. Concerning aldehydes, no  
clear difference between RFO 220 and B30 fuel exhausts was observed before DPF (P1).  
However, aldehyde concentrations 221 (mostly formaldehyde and acetaldehyde) were highly  
increased after DPF (P2) for RFO, but 222 were decreased for B30 blend (Table 1); this supports a  
strong impact of DPF on aldehyde 223 release in the gas phase (Traviss et al., 2010). Altogether,  
our data show an efficiency of DPF 224 to reduce all compounds analyzed in B30 fuel exhaust,  
whereas DPF did not permit to reduce 225 the alkane and aldehyde concentrations in exhaust  
from RFO fuel. Furthermore, we showed 226 that, after DPF, exhaust from RFO fuel contains  
more PAHs than that from B30 fuel, whereas 227 B30 blend-exhaust contains more VOC such as  
**BTEX**.

### 229 *3.2. Analysis of tissue and of biological parameters*

230 Overall, there were no weight change between groups, except in the group of rats exposed  
231 to RFO before DPF (P1), which showed a significant reduction in weight-gain when compared  
232 to their respective filtered air controls (Table S2). Numeration of blood cells did not reveal  
any 233 difference in rats between the different groups (data not shown). Histopathological 234  
examinations did not show major structural lung tissue alteration. It however revealed the 235  
presence of pigmented macrophages in the alveolar space of rats exposed to exhausts in P1, 236  
but not in the group of rats exposed to filtered air nor in the group of rats exposed to both 237  
fuels downstream the DPF (Figure S2). The histological scores of lung inflammation showed 238  
no or a mild inflammation in the lung of rats exposed to filtered air; they were higher in B30- 239  
exposed rats than those in rats exposed to RFO both downstream the DPF (100% of mild- 240  
moderate inflammation versus 44%) and upstream the DPF (83% of mild-moderate 241  
inflammation versus 67%), respectively (Figure S2).

242

### 243 *3.3. Genes differentially expressed in the lung of rats repeatedly exposed to RFO or B30 fuels*

244 The lung gene response of rats exposed to RF0- and B30-exhaust upstream (P1) and  
245 downstream (P2) DPF were first compared, considering a pValue Log-ratio < 0.01 (Fig. 1). We  
246 did not applied a cut-off on the gene expression fold change, because the variations of gene  
247 expression levels were relatively low (not exceeding 2 fold). We first observed that the number  
248 of genes regulated by RF0 (137 genes) and B30 (153 genes) exhaust before DPF (P1) is quite  
249 similar (Fig. 1). The number of regulated genes downstream DPF (P2) was found to be higher  
250 than that before DPF (P1) for both fuels (Fig. 1). In addition, the number of genes regulated by  
251 exposure to B30 fuel after DPF (P2) (781 genes) is 1.8 fold higher than that regulated by  
252 exposure to RF0 fuel (426 genes) downstream DPF (P2) (Fig. 1). The comparison analyses are  
253 presented on the flow chart of the Fig. 1. Venn diagram reveals that only 6 genes are similarly  
254 regulated in rats exposed to RF0 and B30 fuel exhaust before DPF (P1), when compared to  
255 respective control rats, corresponding to about 4 % of the total number of RF0- and B30-  
256 regulated genes before DPF (P1) (Fig. 2A). Similarly, Venn diagram shows that only 35 genes  
257 are regulated in both RF0- and B30-exposed rats downstream DPF, corresponding to 8.2 %  
258 and 4.5 % of standard- and B30-regulated genes, respectively after DPF (P2) (Fig.2B). These  
259 shared regulated genes between RF0 and B30 in P1 and in P2 are listed in Table S3.

260 Because DPF has become mandatory on new diesel engines with the Euro V standard  
261 application since 2011 in European Union, we decided to use our data to gain insight into  
262 health effect of new depollution systems. For this purpose, we employed gene set enrichment  
263 analysis utilizing IPA on the RF0 (426 genes)- and the B30 (781 genes)-related regulated lung  
264 gene lists corresponding to a DPF downstream exposure (P2). The top 5 networks regulated  
265 by exposure to B30 blend exhaust downstream DPF are cancer, cellular assembly and  
266 organization, cellular movement, cell-to-cell interaction and tissue morphology (Table 2A),  
267 whereas the top 5 networks regulated by RF0 fuel exhaust downstream DPF are cellular  
268 development, cellular assembly and organization, lipid metabolism and hematological system  
269 development and function (Table 2B). In spite of the network “cellular assembly and  
270 organization” common to both fuel exposures, only two genes (ERK1/2 and Ppp2c) were found  
271 in both networks, showing a rather weak similarity of gene lists of this network.

272 We next evaluated and compared the top-ranked canonical pathways between RF0 and  
273 B30 fuels downstream the DPF (P2). The significance of all top five canonical pathways in B30-  
274 P2 (Fig. 3A) and in RF0-P2 (Fig. 3B) exceeds the threshold level for all of them. Our data show  
275 that exhaust exposure resulted in activation of some different specific signaling pathways. The

276 first three ranking canonical pathways regulated by B30 blend exhaust are “oxidative  
277 phosphorylation” (p-value =  $1.02 \cdot 10^{-17}$  and ratio 0.25), “mitochondrial dysfunction” (p-value =  
278  $7.04 \cdot 10^{-15}$  and ratio 0.18) and “DNA methylation and transcriptional repression signaling” (p-  
279 value =  $3.83 \cdot 10^{-4}$  and ratio 0.25) (Fig. 3A). The B30 blend-regulated genes associated to these  
280 first two pathways are all identical, plus three new genes in the “mitochondrial dysfunction”  
281 pathway such as GLRX2 (glutaredoxin 2, -1.18 fold), GPX7 (glutathione peroxidase 7, -1.34  
282 fold) and APP (amyloid beta (A4) precursor protein, 1.21 fold) (Table S4). However, no activity  
283 pattern has been identified by z-score, which provides predictions about up or down  
284 processes, for these pathways. Concerning RF0 exposure, p-values of the identified canonical  
285 pathways are weaker than those of B30 exposure. So, the first three ranking canonical  
286 pathways concern “tRNA charging” (p-value =  $5.81 \cdot 10^{-4}$  and ratio 0.12), “regulation of actin-  
287 based motility by Rho” (p-value =  $1.13 \cdot 10^{-3}$  and ratio 0.07) and “Germ cell-Sertoli cell junction  
288 signaling” (p-value =  $2.17 \cdot 10^{-3}$  and ratio 0.05) (Fig. 3B). Analysis of canonical pathways of B30  
289 (P2) sorted by z-score also indicated a positive regulation of “regulation of actin-based motility  
290 by Rho” and “RhoA signaling”; thus RHOA gene, a ras homolog family member A, was found  
291 in common of the second to fifth-ranked pathways (Fig. 3B). Moreover, RAC2 (RAB8B, member  
292 RAS oncogene family) and PAK3 (p21 protein (Cdc42/Rac)-activated kinase 3) were two genes  
293 found in common in the second to fourth pathways.

294 Thus, there is no common top canonical pathway between RF0- and B30-exposed rats  
295 downstream DPF (P2). However, the analysis of the canonical pathways sorted by the z-score  
296 permits to identify 6 pathways in common (Fig. 4). Among them, “Integrin”, “IGF-1” and “Rac  
297 signaling” pathways seem the most activated in lungs of rats exposed to both fuels. Thus, 12  
298 and 8 genes are associated with the “integrin signaling” pathway for B30 and RF0 fuels-  
299 exposed rats respectively, but without shared gene. In contrast, for the “IGF1 signaling”  
300 pathway, 2 genes (among the 7 and 4 genes regulated for the pathway in B30- and RF0-  
301 exposed rats, respectively), *i.e.*, the Protein Kinase CAMP-Dependent Type II Regulatory  
302 Subunit Alpha (PRKAR2A) and the Ribosomal Protein S6 kinase B1 (RPS6KB1), are in common.  
303 This latest gene RPS6KB1, regulated by the mTOR pathway, is also found in the “Rac signaling”  
304 pathway. However, the validation of the fold-expression of these genes by RT-qPCR analysis,  
305 confirms their weak regulation (between 0.8 to 1.3 fold) after an exposure of lungs to fuels  
306 (Table S5). Altogether, our data show a different gene response to RF0 and B30 in the lung of  
307 rats repeatedly exposed to these exhausts downstream DPF; however, it seems that pathways

308 involving membrane receptor (integrin and IGF-1) and Rac signaling, activated by both RFO  
309 and B30 exhausts, could reflect the gaseous phase effects of these both exhausts.

310

#### 311 3.4. *Analysis of the impact of DFP on gene expression in the lung of rats repeatedly exposed* 312 *to B30 fuels*

313 Since there is less data in the literature on biodiesel than diesel and since our p-value data  
314 for regulated genes in response to B30 are strongest that those obtained with exposure to  
315 RFO, we decided to focus on results obtained on lungs from rats exposed to B30 blend. The  
316 number of genes regulated by B30 in P2 (downstream DPF) was 5.1 fold higher than in P1  
317 (upstream DPF) (781 versus 153 genes) (Fig. 5). Venn diagram also reveals that only 31 genes  
318 are common to P1 and P2 when compared to their respective air control, corresponding to  
319 about 20 % and 4% of P1- and P2-regulated genes by B30 exhaust (Fig. 5). Fig. 6 shows the first  
320 ten pathways, sorted by the p-value, in P1 (Fig. 6A) and in P2 (Fig. 6B) conditions for B30  
321 exhaust exposure. Globally, the p-values and the percentages of genes involved in the  
322 canonical pathways from P1 are lower than those found in P2 (Fig. 6). The top five canonical  
323 pathways in the lungs of rats exposed to B30 upstream DPF (P1) are “acute phase response  
324 signaling”, growth hormone signaling”, IL-4 signaling”, “role of JAK2 in hormone-like cytokine  
325 signaling” and “IGF-1 signaling”; however, the percentage of affected genes to the total  
326 number of genes in a pathway is under 10%. Concerning the canonical pathways in the lungs  
327 of rats exposed to B30 exhaust downstream DPF (P2), the highest p-value concerns  
328 “oxidative phosphorylation” and “mitochondrial dysfunction” pathways, with a down-  
329 regulation of almost all genes presents in these pathways. These results were confirmed by a  
330 gene-enrichment and functional annotation analysis, using the DAVID software (data not  
331 shown). The p-values of the 8 other regulated pathways are almost all the same (Fig. 6B). In  
332 contrast to the two first pathways, genes involved in the “DNA methylation and  
333 transcriptional repression signaling”, ranking third, seems overexpressed. In contrast to what  
334 we observed for genes regulated by DPF upstream exposure to B30 exhaust (P1), the  
335 percentage of affected genes to the total number of genes in a pathway is equal or over 10%  
336 for the top five pathways regulated downstream DPF (P2). The “p70S6K signaling” is found  
337 present both in P1- and in P2- condition exposures (Fig. 6) with only one gene in common,  
338 i.e., RPS6KB1, previously identified also in RFO exhaust exposure (P2).

339 Results of RT-qPCR analysis confirmed some microarray data. Thus, six selected genes from  
340 the two first regulated pathways exhibited a significant repression in the lungs of B30 (P2)  
341 exhaust-exposed rats (Fig.7). The mRNA expression of four genes of the mitochondrial NADH  
342 dehydrogenase [ubiquinone] 1 from the respiratory chain complex I (Ndufa2, Ndufa6, Ndubf2  
343 and Ndufc1) and one of the complex V (ATP Synthase Subunit O (Atp5o)) were notably  
344 significantly reduced in comparison to the air control group. The down-expression of these  
345 genes was significant after exposure to B30 (P2) when compared both to control or to B30  
346 (P1), except for Ndufa6 (Fig. 7). Even if the genes of the mitochondria respiratory chain have  
347 not been identified as differentially regulated in the lung samples of rat exposed to RFO  
348 exhaust by the microarray analysis, RT-qPCR assays indicated that their mRNA expressions  
349 were also reduced in P2, in a similar way than those exposed to B30 exhaust in P2. In addition,  
350 the mRNA expression of glutathione peroxidase 7 (Gpx7), identified in the “mitochondrial  
351 dysfunction” pathway and whose biological role is to protect the organism from oxidative  
352 damage, was also significantly reduced in P2 groups exposed to B30 or RFO exhausts (Fig. 7).

353 In order to better characterize the gene signature of the gaseous phase of B30 exhausts,  
354 we compared the top forty canonical pathways sorted first on the p-value and then on the z-  
355 score of B30 in P2. The results presented in the Table S6 show that the pathways with the  
356 highest score are “integrin-”, “oncostatin M-”, “VEGF-“, “EGF-“, “Rac-“ and “IGF-1-signaling”  
357 and the “remodeling of epithelial adherens junctions”. Five canonical pathways have a positive  
358 z-score  $\geq 2$ , suggesting an activation of these pathways by the gaseous phase of B30 blend  
359 exhaust. By contrast, the “mTOR signaling” pathway seems decreased. Because “integrin  
360 signaling”, “Rac signaling” and “IGF-1 signaling” ways have been previously identified in the  
361 lungs of rats exposed to RFO exhaust downstream DPF (P2) such as to those exposed to B30 in  
362 P2 (Fig. 4), the others pathways cited could be specific to the gaseous phase of B30 exhausts.

363

#### 364 4. Discussion

365 The present study is part of a research project aiming to better characterize the toxicity of  
366 biodiesel exhausts from modern engines, notably by comparing their effects to those of RFO  
367 and the impact of the depollution system DPF. For this purpose, the whole genome RNA  
368 expression microarray covering 20 K of gene transcripts was used. The major results of the  
369 present study are as follow: 1) the levels of transcript deregulation in the lung of rats  
370 repeatedly exposed to diesel blend exhaust were rather weak (gene expression variations are



371 less than 2-fold), 2) the transcriptomic profile of changes due to B30 exhaust was different to  
372 that related to RFO exhaust, 3) a higher number of transcripts was deregulated by B30  
exhaust 373 downstream the depollution system than before DPF; 4) the lung transcript profile of  
B30- 374 exposed rats was modified by the presence of the DPF, demonstrating an impact of the  
375 depollution system on lung tissue and 5) the repeated exposure to the gaseous phase of B30  
376 seems associated to mitochondrial dysfunction.

377 At the animal level, repeated subacute exposure to RFO and B30 exhausts was not  
378 accompanied by apparent toxicity, except a lower weight gain for rats exposed to RFO 379  
upstream DPF. The absence of lung tissue injuries in rats exposed to diesel exhausts are in 380  
accordance with previous reports showing modest lung adverse effects of chronic soybean 381  
(Bass et al., 2015; Finch et al., 2002) or rapeseed oil-derived fuel exposure in rats (Magnusson 382  
et al., 2017). While no inflammatory pathway has been identified in the transcriptomic data 383  
from lung tissue, histological analysis revealed a mild to moderate inflammation in airways of 384  
rats exposed to diesel emissions, especially to B30 exhausts. As mitochondrial dysfunction 385  
may be linked to inflammatory responses (Lopez-Armada et al, 2013), our transcriptomic data 386  
support the histological observations. Because of such mild lung inflammation, we cannot 387  
argue that the genomic signatures reflect only the molecular changes within lung resident cell 388  
population, but also probably those of infiltrated cells.

389 The efficiency of the DPF was confirmed by the near absence of PM downstream the DPF  
390 and, at the histological level, by the absence of pigmented alveolar macrophages in lung of  
391 rats exposed downstream to this depollution system. Thus, BTEX concentrations were  
strongly 392 reduced in exhausts downstream of DPF both for RFO and B30 fuels; a similar effect  
of DPF on 393 B30 exhausts was also observed with alkanes and PAHs, whose concentrations  
decrease, as 394 previously described for PAHs in B20 exhaust (Magnusson et al., 2017). By  
contrast, no DPF- 395 related reduction of standard diesel pollutant emissions has been observed  
for alkanes and 396 PAHs and, on the contrary, aldehyde concentrations were found strongly  
increased. This last 397 result indicates that DPF may have change the composition of exhausts.  
As formaldehyde may 398 be an intermediate product from others aldehydes or hydrocarbons  
during oxidation reaction 399 in catalyst, its decrease in exhausts from B30 in comparison to  
those of RFO may be related to 400 the 30% dilution of diesel and thus to the lowest  
concentration of such initial compounds in 401 B30 blend. Therefore, the depollution system DPF  
used in our experimental conditions mainly 402 modifies the composition of B30 exhausts.  
However, despite such decreases of exhaust

403 concentrations, the number of regulated genes by B30 emissions was higher downstream  
than 404 upstream the DPF. Such data were rather surprising since an opposite situation was  
previously 405 observed in cardiac tissue of rats exposed to diesel emissions (Karoui et al, 2019),  
suggesting 406 some specific tissue response to gas phase of exhaust or to remaining ultrafine  
~~PM10~~. Because of these modifications of exhaust composition after the DPF, a differential gene  
408 expression profile related to the presence of this depollution system was expected. Indeed,  
409 our transcriptomic data argue in favor of a specific response of rat lungs to B30 exhausts in  
410 function of the presence or not of DPF. Major canonical pathways identified are different,  
411 except the “p70S6K signaling”. However, the few number of genes associated to this pathway  
412 and the weak level of expression regulation do not permit to consider it as a global B30-related  
413 exhaust exposure signature. By contrast, “oxidative phosphorylation” and “mitochondrial  
414 dysfunction” pathways are only identified downstream of DPF; the down-regulation of genes  
415 associated to the mitochondrial respiratory chain, validated by RT-qPCR, confirms a gene-  
416 specific signature for lungs of rats exposed to exhaust emitted downstream the DPF. Indeed,  
417 the same profile of mitochondrial gene expression was found in lungs of rat exposed to Rf0  
418 downstream of DPF, suggesting that the gaseous fraction of exhaust may be the primary driver  
419 of the observed effects. The impact of the down-expression of genes from mitochondria  
420 respiratory chain should be evaluated by the measure of ATP production or by the oxygen  
421 consumption, to fully confirm the toxic effects of diesel exhausts towards mitochondria from  
422 lungs. Interestingly, previous studies demonstrated that adsorbed chemicals on DEP, such as  
423 PAHs, altered mitochondria functions (Xia et al., 2004) and that DEP extracts induce apoptosis  
424 of macrophages, via toxic effects on mitochondria, in association with reactive oxygen species  
425 (ROS) production (Hiura et al., 2000). In our experimental conditions, we did not however  
426 find any ROS production in lung tissues of rats exposed sub-chronically to Rf0 or B30 (Douki  
427 et al., 2018). Nevertheless, a functional alteration of mitochondria respiratory chain was  
428 demonstrated in the myocardium of rats exposed to Rf0 in the same conditions that those of  
429 the present study (Karoui et al., 2019), suggesting that a similar effect could also be expected  
430 in the lung. Also, the identification of the “oxidative phosphorylation” pathway in mice 431  
exposed to diesel exhaust (Stevens et al., 2008) and the role of mitochondria previously 432  
reported in pulmonary diseases such as asthma (Cloonan and Choi, 2016), whose 433  
exacerbations are often related to exposure to diesel exhaust (Alexis and Carlsten, 2014), 434  
support our data on lung mitochondrial dysfunction after a diesel exhaust exposure. In any

435 case, it is difficult to attribute the toxic effects on mitochondria of diesel exhausts to a specific  
436 pollutant that we have measured, at least in part because B30 but also RFO exhausts have  
437 altered mitochondria respiratory chain gene expression, whereas concentrations of BTEX,  
438 aldehydes, alkanes, PAHs, NO, NOX and CO have been found to differ downstream of DPF.

439 By contrast, the differences in concentrations of gaseous pollutants may explain the poor  
440 overlapping of transcript expression that we observed between both fuels. So, the addition of  
441 30% of rapeseed methylester was efficient to reduce aldehyde and alkane concentrations  
442 (Bakeas and Karavalakis, 2013) as well as those of PAHs, but not BTEX concentrations. The  
443 nature of PAHs was found to differ between RFO and B30 exhausts, i.e., naphthalene 444  
concentration was higher in RFO than B30, whereas the fluoranthene and pyrene 445  
concentrations were higher in B30 than RFO. So, the greater number of regulated genes in 446  
lung of rat exposed to B30 compared to those exposed to RFO may be related at least in part 447  
to the higher concentrations of fluoranthene, pyrene, NO, NOx and VOCs such as BTEX, 448  
especially of xylene. In spite of the low numbers of genes regulated in common in response to 449  
RFO and B30 exhaust exposure downstream DPF (P2), that can be explain by the difference in 450  
PAH nature and the lowest concentration of BTEX (in RFO versus B30), three pathways 451  
(integrin-, IGF-1- and Rac-signaling) were considered as activated for both fuel exhausts, which 452  
could represent the gaseous phase profile for both diesel exhausts. Integrins are major 453  
membrane proteins involved in cell-cell or cell-matrix interactions and integrin engagement 454  
regulates the activity of several members of small GTPases such as RhoA or Rac1, which 455  
control the cell contraction and migration. Integrin expression was altered by an exposure to 456  
diesel exhausts in human airway epithelial cells (Doornaert et al., 2003; Le Vee et al., 2016) 457  
and also in lung biopsies of human volunteers after a short term exposure to diesel exhaust 458  
(Salvi et al., 1999), suggesting that fuel exhausts may alter lung tissue homeostasis through 459  
impairing integrin-mediated cell adhesion. Insulin like Growth Factor (IGF-)-1 signaling 460  
pathway regulates multiple cellular processes, including proliferation, differentiation, energy 461  
metabolism or glucose homeostasis. IGF-1R is highly expressed in lung epithelial cells, alveolar 462  
macrophages and smooth muscle (López et al., 2016) and binding of ligands to IGF-1 receptor 463  
leads to its activation and the subsequent activation of Shc/RAS/RAF/ERK-MAPK or 464 IRS/PI3K/  
AKT/mTOR pathways, which promotes cell proliferation. Such signaling pathway 465 activation is  
consistent with (i) the increased level of IGF signaling genes were increased in the 466 lung of  
mice exposed to naphthalene, a PAH known to alter airway epithelium and present in

467 diesel fuel exhaust (López et al., 2016), and (ii) the increase of IGF-1 plasma levels in traffic  
468 policemen exposed to urban pollutants (Tomei et al., 2004).

469 Our study has some limitations. First, our transcriptomic analysis was only done after a  
470 repeated exposure to diesel exhausts, without comparison to a short/acute exposure that  
471 would be informative on the kinetic of transcript expression profile of lung tissue exposed to  
472 diesel blend. Second, this transcriptomic study could have been carried with a more recent  
473 and more efficient approaches, such as the next-generation sequencing (NGS), but when this  
474 study began, NGS was quite expensive and not so spread. Third, it would have been  
interesting 475 to complete our study on the inflammatory response after exposure to diesel  
emissions with 476 an analysis of inflammatory secreted markers in the broncho-alveolar  
lavages; this was 477 however not possible to do it, because the full lung of each animal was  
required for other 478 studies performed by our research consortium (Douki et al., 2018).

479

## 480 **5. Conclusion**

481 In summary, using a genomic analysis, we have identified different genes and pathways  
482 regulated in lungs of rats repeated exposed to standard diesel or to 30% rapeseed methyl  
483 ester. In accordance with previous data published by our research consortium (Douki et al.,  
484 2018 ; Karoui et al, 2019), we confirmed that the gaseous phase may have a higher impact,  
485 but remaining anyway moderate, on lung tissue than the complete exhausts.

486

## 487 **Conflicts of interests**

488 The authors have no conflict to interest to declare.

489

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497

## 498 **Author contributions**

499 Conceived and designed the experiments: VL. CM. TD. FS. OF. Performed the experiments: VL.  
500 CM. MJ. FC. PG. Contribute to reagents/materials/analysis tools: CC. DP. Wrote the article: VL.  
501 OF.

502

## 503 **References**

504 Alexis, N.E., Carlsten, C., 2014. Interplay of air pollution and asthma immunopathogenesis: a  
505 focused review of diesel exhaust and ozone. *Int. Immunopharmacol.* 23, 347–355.

506 Anselme, F., Lorient, S., Henry, J.-P., Dionnet, F., Napoleoni, J.-G., Thuillez, C., Morin, J.-P., 2007.  
507 Inhalation of diluted diesel engine emission impacts heart rate variability and arrhythmia  
508 occurrence in a rat model of chronic ischemic heart failure. *Arch. Toxicol.* 81, 299–307.

509 Bakeas, E.B., Karavalakis, G., 2013. Regulated, carbonyl and polycyclic aromatic hydrocarbon  
510 emissions from a light-duty vehicle fueled with diesel and biodiesel blends. *Environ Sci*  
511 *Process Impacts* 15, 412–422.

512 Bass, V.L., Schladweiler, M.C., Nyska, A., Thomas, R.F., Miller, D.B., Krantz, T., King, C., Ian  
513 Gilmour, M., Ledbetter, A.D., Richards, J.E., Kodavanti, U.P., 2015. Comparative  
514 cardiopulmonary toxicity of exhausts from soy-based biofuels and diesel in healthy and  
515 hypertensive rats. *Inhal Toxicol* 27, 545–556.

516 Beer, T., Grant, T., Campbell, P.K. 2007. The greenhouse and air quality emissions of biodiesel  
517 blends in Australia: report for Caltex Australia limited. Aspendale: CSIRO Marine and  
518 Atmospheric Research; Report No.:KS54C/1/F2.29.

519 Bünger, J., Krahel, J., Schröder, O., Schmidt, L., Westphal, G.A., 2012. Potential hazards  
520 associated with combustion of bio-derived versus petroleum-derived diesel fuel. *Crit. Rev.*  
521 *Toxicol.* 42, 732–750.

522 Cloonan, S.M., Choi, A.M.K., 2016. Mitochondria in lung disease. *J. Clin. Invest.* 126, 809–820.

523 Cohen, A.J., Brauer, M., Burnett, R., Anderson, H.R., Frostad, J., Estep, K., Balakrishnan, K.,  
524 Brunekreef, B., Dandona, L., Dandona, R., Feigin, V., Freedman, G., Hubbell, B., Jobling, A.,  
525 Kan, H., Knibbs, L., Liu, Y., Martin, R., Morawska, L., Pope, C.A., Shin, H., Straif, K., Shaddick,  
526 G., Thomas, M., van Dingenen, R., van Donkelaar, A., Vos, T., Murray, C.J.L., Forouzanfar,  
527 M.H., 2017. Estimates and 25-year trends of the global burden of disease attributable to  
528 ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015.  
529 *Lancet* 389, 1907–1918.

530 Doornaert, B., Leblond, V., Galiacy, S., Gras, G., Planus, E., Laurent, V., Isabey, D., Lafuma, C.,  
531 2003. Negative impact of DEP exposure on human airway epithelial cell adhesion, stiffness,  
532 and repair. *Am. J. Physiol. Lung Cell Mol. Physiol.* 284, L119-132.

533 Douki, T., Corbière, C., Preterre, D., Martin, P.J., Lecureur, V., André, V., Landkocz, Y., Pottier,  
534 I., Keravec, V., Fardel, O., Moreira-Rebello, S., Pottier, D., Vendeville, C., Dionnet, F., Gosset,

535 P., Billet, S., Monteil, C., Sichel, F., 2018. Comparative study of diesel and biodiesel exhausts  
536 on lung oxidative stress and genotoxicity in rats. *Environ. Pollut.* 235, 514–524.

537 European Environment Agency. [https://www.eea.europa.eu/data-and-](https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-air-pollutants-8/transport-emissions-of-air-pollutants-8)  
538 [maps/indicators/transport-emissions-of-air-pollutants-8/transport-emissions-of-air-](https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-air-pollutants-8/transport-emissions-of-air-pollutants-8)  
539 [pollutants-8](https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-air-pollutants-8/transport-emissions-of-air-pollutants-8) (accessed 07 April 2020).

540 Finch, G.L., Hobbs, C.H., Blair, L.F., Barr, E.B., Hahn, F.F., Jaramillo, R.J., Kubatko, J.E., March,  
541 T.H., White, R.K., Krone, J.R., Ménache, M.G., Nikula, K.J., Mauderly, J.L., Van Gerpen, J.,  
542 Merceica, M.D., Zielinska, B., Stankowski, L., Burling, K., Howell, S., 2002. Effects of  
543 subchronic inhalation exposure of rats to emissions from a diesel engine burning soybean  
544 oil-derived biodiesel fuel. *Inhal Toxicol* 14, 1017–1048.

545 GBD 2016 Risk Factors Collaborators, 2017. Global, regional, and national comparative risk  
546 assessment of 84 behavioural, environmental and occupational, and metabolic risks or  
547 clusters of risks, 1990-2016: a systematic analysis for the Global Burden of Disease Study  
548 2016. *Lancet* 390, 1345–1422.

549 Ghio, A.J., Smith, C.B., Madden, M.C., 2012. Diesel exhaust particles and airway inflammation.  
550 *Curr Opin Pulm Med* 18, 144–150.

551 Godri Pollitt, K.J., Chhan, D., Rais, K., Pan, K., Wallace, J.S., 2019. Biodiesel fuels: A greener  
552 diesel? A review from a health perspective. *Sci. Total Environ.* 688, 1036–1055.

553 Hiura, T.S., Li, N., Kaplan, R., Horwitz, M., Seagrave, J.C., Nel, A.E., 2000. The role of a  
554 mitochondrial pathway in the induction of apoptosis by chemicals extracted from diesel  
555 exhaust particles. *J. Immunol.* 165, 2703–2711.

556 Karoui, A., Crochemore, C., Mulder, P., Preterre, D., Cazier, F., Dewaele, D., Corbière, C., Mekki,  
557 M., Vendeville, C., Richard, V., Vaugeois, J.-M., Fardel, O., Sichel, F., Lecreur, V., Monteil,  
558 C., 2019. An integrated functional and transcriptomic analysis reveals that repeated  
559 exposure to diesel exhaust induces sustained mitochondrial and cardiac dysfunctions.  
560 *Environ. Pollut.* 246, 518–526.

561 Le Vee, M., Jouan, E., Lecreur, V., Fardel, O., 2016. Aryl hydrocarbon receptor-dependent up-  
562 regulation of the heterodimeric amino acid transporter LAT1 (SLC7A5)/CD98hc (SLC3A2) by  
563 diesel exhaust particle extract in human bronchial epithelial cells. *Toxicol. Appl. Pharmacol.*  
564 290, 74–85.

565 López, I.P., Piñero-Hermida, S., Pais, R.S., Torrens, R., Hoeflich, A., Pichel, J.G., 2016.  
566 Involvement of Igf1r in Bronchiolar Epithelial Regeneration: Role during Repair Kinetics  
567 after Selective Club Cell Ablation. *PLoS ONE* 11, e0166388.

568 Lopez-Armada MJ, Riveiro-Naveira RR, Vaamonde-Garcia C, Valcarcel-Ares MN (2013) Mitochondrial  
569 dysfunction and the inflammatory response. *Mitochondrion* 13: 106-118.

570 Magnusson, P., Dziendzikowska, K., Oczkowski, M., Øvrevik, J., Eide, D.M., Brunborg, G.,  
571 Gutzkow, K.B., Instanes, C., Gajewska, M., Wilczak, J., Sapierzynski, R., Kamola, D.,  
572 Królikowski, T., Kruszewski, M., Lankoff, A., Mruk, R., Duale, N., Gromadzka-Ostrowska, J.,

573 Myhre, O., 2019. Lung effects of 7- and 28-day inhalation exposure of rats to emissions  
574 from 1st and 2nd generation biodiesel fuels with and without particle filter - The FuelHealth  
575 project. *Environ. Toxicol. Pharmacol.* 67, 8–20.

576 Magnusson, P., Oczkowski, M., Øvrevik, J., Gajewska, M., Wilczak, J., Biedrzycki, J.,  
577 Dziendzikowska, K., Kamola, D., Królikowski, T., Kruszewski, M., Lankoff, A., Mruk, R.,  
578 Brunborg, G., Instanes, C., Gromadzka-Ostrowska, J., Myhre, O., 2017. No adverse lung  
579 effects of 7- and 28-day inhalation exposure of rats to emissions from petrodiesel fuel  
580 containing 20% rapeseed methyl esters (B20) with and without particulate filter - the  
581 FuelHealth project. *Inhal Toxicol* 29, 206–218.

582 Maresh, J.G., Campen, M.J., Reed, M.D., Darrow, A.L., Shohet, R.V., 2011.  
583 Hypercholesterolemia potentiates aortic endothelial response to inhaled diesel exhaust.  
584 *Inhal Toxicol* 23, 1–10.

585 Miller, M.R., Shaw, C.A., Langrish, J.P., 2012. From particles to patients: oxidative stress and  
586 the cardiovascular effects of air pollution. *Future Cardiol* 8, 577–602.

587 Morin, JP., Gouriou, F., Preterre, D., Bobbia, M., Delmas, V., 2009. Evaluation de l'exposition  
588 aux polluants atmospheriques des conducteurs de véhicules automobiles par la mise en  
589 œuvre de mesures dynamiques dans l'habitacle du véhicule. *Arch. Maladies Prof.*  
590 *Environnement* 70, 184e192.

591

592 Nemmar, A., Hoet, P.H.M., Vanquickenborne, B., Dinsdale, D., Thomeer, M., Hoylaerts, M.F.,  
593 Vanbilloen, H., Mortelmans, L., Nemery, B., 2002. Passage of inhaled particles into the  
594 blood circulation in humans. *Circulation* 105, 411–414.

595 Nemmar, A., Vanbilloen, H., Hoylaerts, M.F., Hoet, P.H., Verbruggen, A., Nemery, B., 2001.  
596 Passage of intratracheally instilled ultrafine particles from the lung into the systemic  
597 circulation in hamster. *Am. J. Respir. Crit. Care Med.* 164, 1665–1668.

598 Pettit, A.P., Brooks, A., Laumbach, R., Fiedler, N., Wang, Q., Strickland, P.O., Madura, K., Zhang,  
599 J., Kipen, H.M., 2012. Alteration of peripheral blood monocyte gene expression in humans  
600 following diesel exhaust inhalation. *Inhal Toxicol* 24, 172–181.

601 Pope, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D., 2002. Lung  
602 cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air  
603 pollution. *JAMA* 287, 1132–1141.

604 Ristovski, Z.D., Miljevic, B., Surawski, N.C., Morawska, L., Fong, K.M., Goh, F., Yang, I.A., 2012.  
605 Respiratory health effects of diesel particulate matter. *Respirology* 17, 201–212.

606 Salvi, S., Blomberg, A., Rudell, B., Kelly, F., Sandström, T., Holgate, S.T., Frew, A., 1999. Acute  
607 inflammatory responses in the airways and peripheral blood after short-term exposure to  
608 diesel exhaust in healthy human volunteers. *Am. J. Respir. Crit. Care Med.* 159, 702–709.

609 Selley, L., Phillips, D.H., Mudway, I., 2019. The potential of omics approaches to elucidate  
610 mechanisms of biodiesel-induced pulmonary toxicity. *Part Fibre Toxicol* 16, 4.

- 611 Srivastava, A., Sharma, A., Yadav, S., Flora, S.J.S., Dwivedi, U.N., Parmar, D., 2014. Gene  
612 expression profiling of candidate genes in peripheral blood mononuclear cells for  
613 predicting toxicity of diesel exhaust particles. *Free Radic. Biol. Med.* 67, 188–194.
- 614 Steiner, S., Bisig, C., Petri-Fink, A., Rothen-Rutishauser, B., 2016. Diesel exhaust: current  
615 knowledge of adverse effects and underlying cellular mechanisms. *Arch Toxicol* 90, 1541–  
616 1553.
- 617 Stevens, T., Krantz, Q.T., Linak, W.P., Hester, S., Gilmour, M.I., 2008. Increased transcription  
618 of immune and metabolic pathways in naive and allergic mice exposed to diesel exhaust.  
619 *Toxicol. Sci.* 102, 359–370.
- 620 Tomei, F., Ciarrocca, M., Rosati, M.V., Baccolo, T.P., Fiore, P., Perrone, P., Tomao, E., 2004.  
621 Occupational exposure to urban pollutants and plasma insulin-like growth factor 1 (IGF-1).  
622 *Int J Environ Health Res* 14, 135–142.
- 623 Traviss, N., Thelen, B.A., Ingalls, J.K., Treadwell, M.D., 2010. Biodiesel versus diesel: a pilot  
624 study comparing exhaust exposures for employees at a rural municipal facility. *J Air Waste*  
625 *Manag Assoc* 60, 1026–1033.
- 626 Valand, R., Magnusson, P., Dziendzikowska, K., Gajewska, M., Wilczak, J., Oczkowski, M.,  
627 Kamola, D., Królikowski, T., Kruszewski, M., Lankoff, A., Mruk, R., Marcus Eide, D.,  
628 Sapieryński, R., Gromadzka-Ostrowska, J., Duale, N., Øvrevik, J., Myhre, O., 2018. Gene  
629 expression changes in rat brain regions after 7- and 28 days inhalation exposure to exhaust  
630 emissions from 1st and 2nd generation biodiesel fuels - The FuelHealth project. *Inhal*  
631 *Toxicol* 30, 299–312.
- 632 Weitekamp, C.A., Kerr, L.B., Dishaw, L., Nichols, J., Lein, M., Stewart, M.J., 2020. A systematic  
633 review of the health effects associated with the inhalation of particle-filtered and whole  
634 diesel exhaust. *Inhal Toxicol* 32, 1–13.
- 635 Xia, T., Korge, P., Weiss, J.N., Li, N., Venkatesen, M.I., Sioutas, C., Nel, A., 2004. Quinones and  
636 aromatic chemical compounds in particulate matter induce mitochondrial dysfunction:  
637 implications for ultrafine particle toxicity. *Environ. Health Perspect.* 112, 1347–1358.
- 638 Yanagisawa, R., Takano, H., Inoue, K., Ichinose, T., Yoshida, S., Sadakane, K., Takeda, K.,  
639 Yoshino, S., Yamaki, K., Kumagai, Y., Yoshikawa, T., 2004. Complementary DNA microarray  
640 analysis in acute lung injury induced by lipopolysaccharide and diesel exhaust particles. *Exp.*  
641 *Biol. Med. (Maywood)* 229, 1081–1087.

642



643 **Legends of Figures:**

644

645 **Figure 1:** Flow chart of exposure conditions and microarray analysis of rat lung tissue  
646 indicating the essential experimental and data analysis. For each exposure campaign, three  
647 groups of six rats were exposed to filtered air or to reference diesel (RF0) or 30% rapeseed  
648 biofuel (B30), upstream and downstream of diesel particle filter (DPF). After RNA extraction  
649 and validation of RNA quality, lung gene expression profiles were determined using  
650 GeneChip® RAGENE 2.0 ST Arrays.

651

652 **Figure 2:** Presentation by Venn Diagram of the differentially expressed genes in lungs of rats  
653 exposed to exhausts upstream DPF (P1) (A) and downstream DPF (P2) (B), when compared to  
654 their respective filtered air controls. Genes were selected on the basis of a p-Value Log-ratio  
655  $\leq 0.01$

656

657 **Figure 3:** Five top canonical pathways regulated by B30 exhaust in P2 versus air control (A) or  
658 regulated by RF0 exhaust in P2 versus air control (B), sorted by the p-value. Bars represent -  
659  $\log(p\text{-value})$  of affected genes in the selected pathways; yellow lines represent the ratio of  
660 affected genes to the total number of genes in a pathway. Threshold (yellow dotted lines)  
661 denote the  $p=0.01$  level.

662

663 **Figure 4:** Comparison of the 6 top canonical pathways sorted by z-score between rat lungs  
664 exposed to RF0 and B30 fuel exhaust downstream DPF (P2).

665 **Figure 5:** Presentation by Venn diagram of the number of genes differentially expressed in  
666 lungs of rats exposed to B30 upstream DPF (in P1) and downstream DPF (in P2), when  
667 compared to the filtered air control. Genes were selected on the basis of a p-Value Log-ratio  
668  $\leq 0.01$ .

669 **Figure 6:** Ten top canonical pathways of B30 exhaust upstream DPF (P1) (A) and downstream  
670 DPF (P2) (B). Bars represent the percentage of affected genes to the total number of genes in  
671 a pathway; in green, genes down-regulated and in red genes, up-regulated in the pathway.  
672 Yellow lines represent  $-\log(p\text{-value})$  of affected genes in the selected pathways.

673 **Figure 7:** RT-qPCR analysis of gene expression in lungs from rats exposed to RFO or B30  
674 exhausts upstream (P1) or downstream DPF (P2). Analyzed genes were selected from the  
675 “mitochondrial dysfunction” pathway. Data are expressed as -fold change gene expression  
676 when compared to control and are the means  $\pm$  SEM of 6 lung samples. t-Test analysis: \*:  
677  $p < 0.05$ ; \*\*:  $p < 0.01$  vs their respective air control identified by a dashed line. #:  $p < 0.05$ ; ##:  
678  $p < 0.01$ .

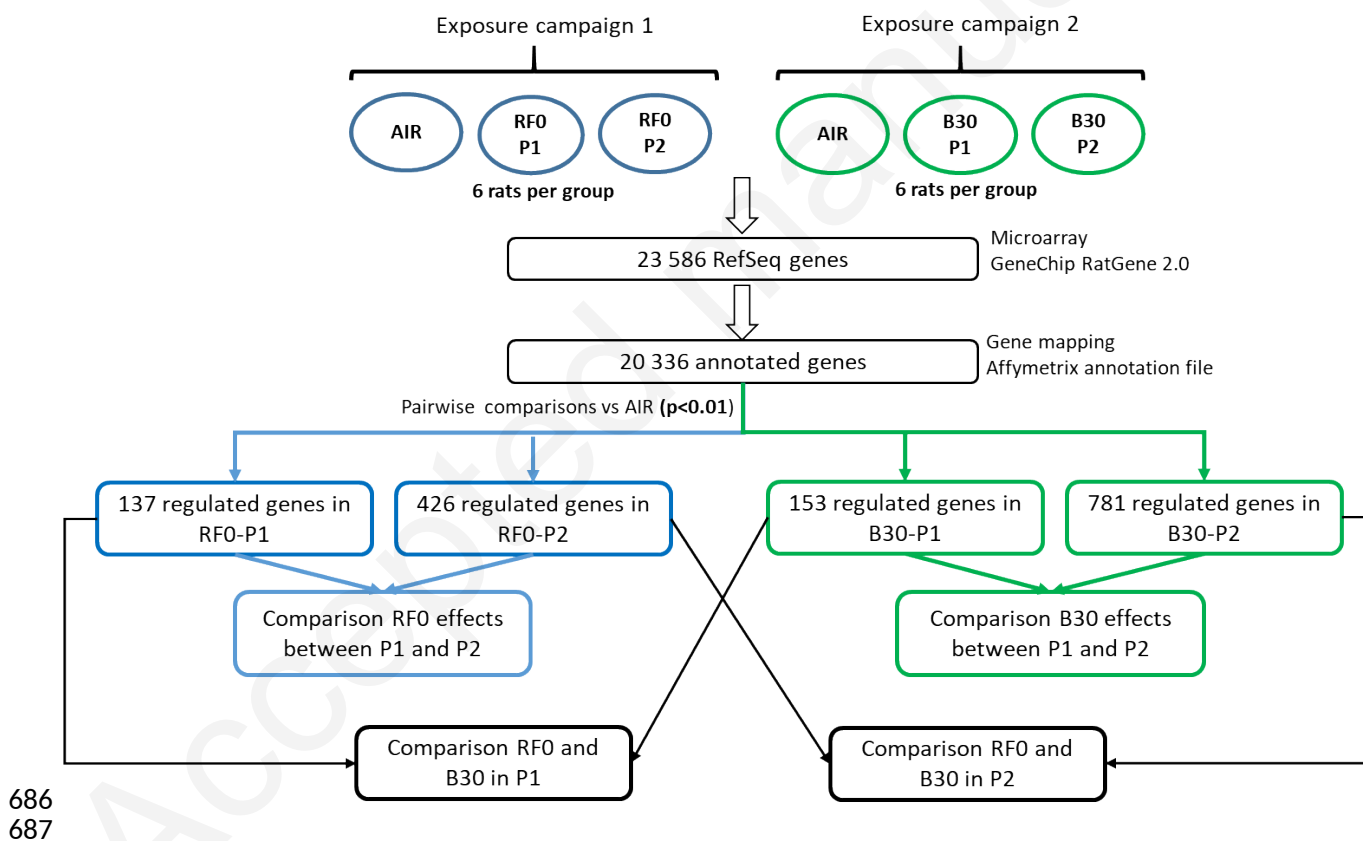
Accepted manuscript

679 **Table 1:** BTEX (Benzene, Toluene, Ethylbenzene, Xylene), aldehydes, alkanes (from C8 to C40)  
 680 and Polycyclic Aromatic Hydrocarbons (PAHs) concentrations in  $\mu\text{g}/\text{m}^3$  in samples from RF0 or  
 681 B30 exhausts collected upstream of the diesel particle filter (DPF) (P1) or downstream the DPF  
 682 (P2). Two measures were done for each exposure campaign.

Chemicals ( $\mu\text{g}/\text{m}^3$ )	Standard fuel (RF0)					Fuel mix (B30)				
	P1 measure	P1 measure	P2 measure	P2 measure	Range of Ratio P2/P1	P1 measure	P1 measure	P2 measure	P2 measure	Range of Ratio P2/P1
BTEX	45,8	53,6	4,17	7,80	0,09-0,15	82,2	218,9	24,2	124,7	0,3-0,6
aldehydes	37,3	44,2	182,9	194,3	4,4-4,9	13,5	36,1	14,2	11,3	0,3-1,1
alkanes (C8-C40)	124,3	341,5	438,3	133,9	0,4-3,5	368,0	177,8	63,9	66,4	0,2-0,4
PAHs	1,02	9,89	5,79	3,51	0,4-5,7	4,04	2,38	0,58	0,07	0,03-0,14

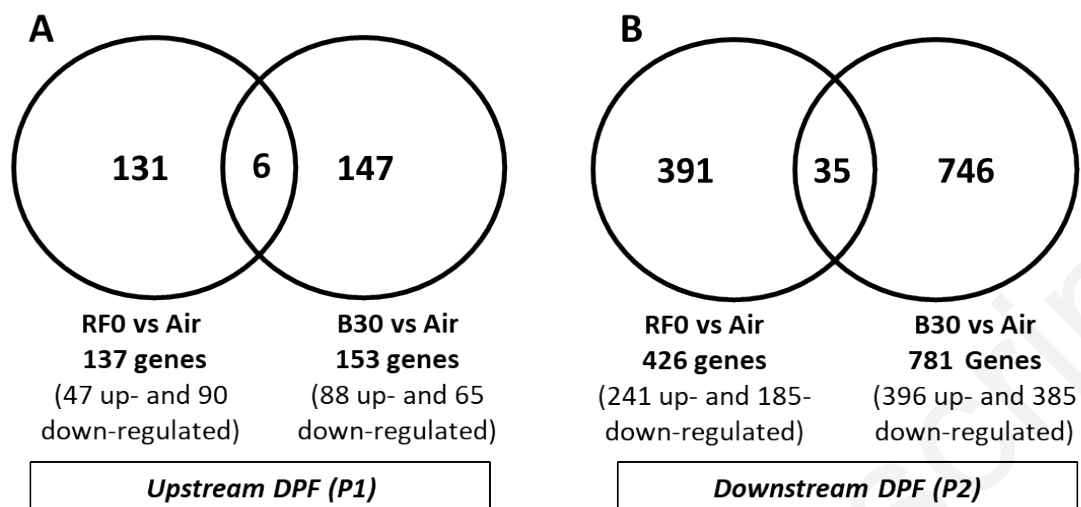
684

685 **Figure 1:**



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688 **Figure 2 :**



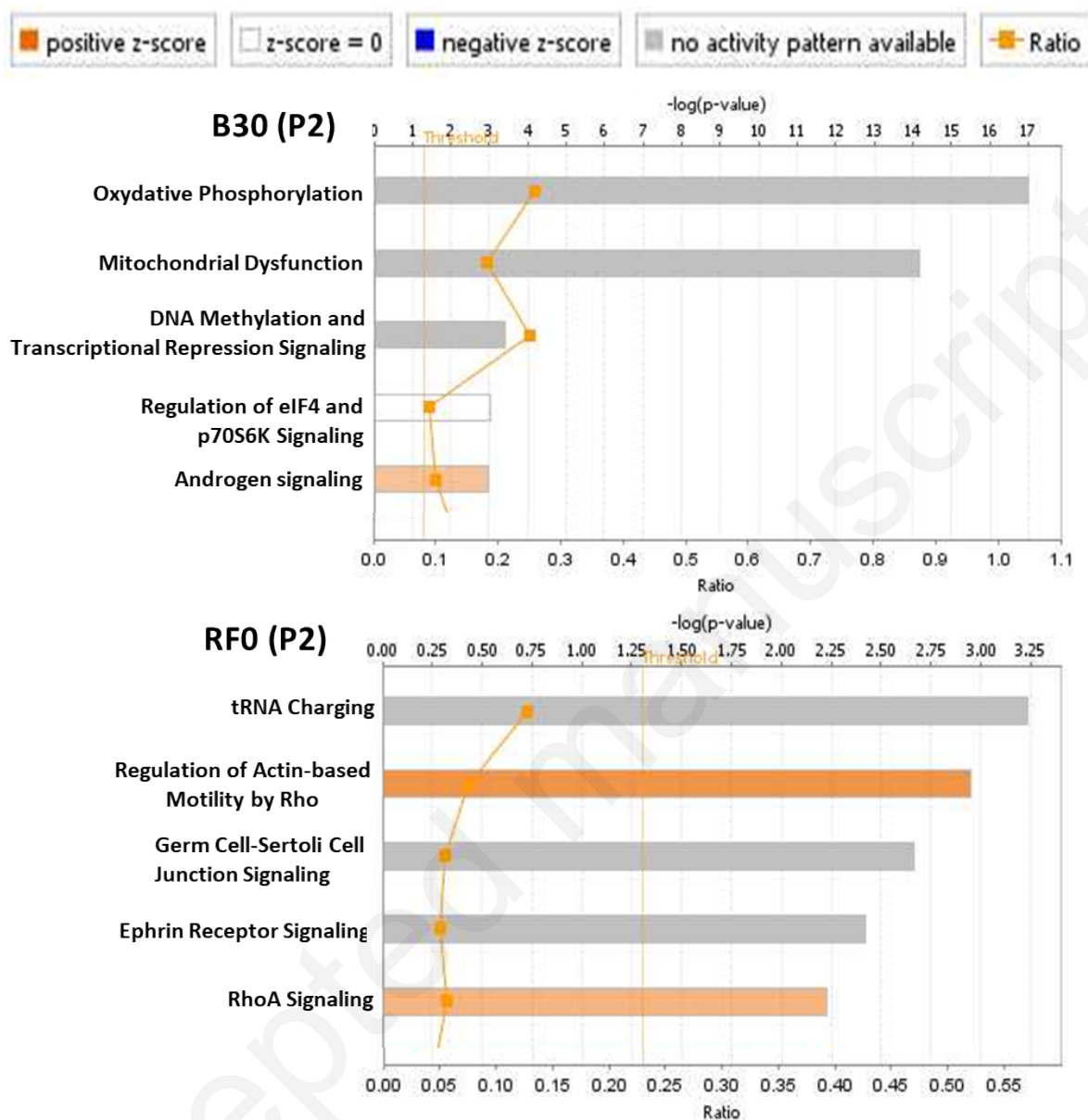
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690 **Table 2: Top Network of B30 P2 (A) and RFO P2 (B)**

<b>A</b>	<b>Top Diseases and Functions (B30 P2 versus air control)</b>	<b>Score</b>	<b>Diff expressed genes in pathway</b>
1	Cancer, Gene Expression, Cellular Development	45	33
2	Cellular Assembly and Organization, Cellular Function and Maintenance, Cell Death and Survival	34	28
3	Cellular Movement, Cell-To-Cell Signaling and Interaction, Hair and Skin Development and Function	34	27
4	Cell-To-Cell Signaling and Interaction, Tissue Development, Cellular Assembly and Organization	30	25
5	Tissue Morphology, Metabolic Disease, Cellular Development	30	26
<b>B</b>	<b>Top Diseases and Functions (RFO P2 versus air control)</b>	<b>Score</b>	<b>Diff expressed genes in pathway</b>
1	Cellular Development, Nervous System Development and Function, Skeletal and Muscular System Development and Function	37	26
2	Cellular Assembly and Organization, Cellular Development, Cellular Growth and Proliferation	33	24
3	Cellular Assembly and Organization, Cellular Function and Maintenance, Protein Synthesis	31	23
4	Lipid Metabolism, Small Molecule Biochemistry, Developmental Disorder	27	21
5	Hematological System Development and Function, Inflammatory Response, Tissue Morphology	22	18

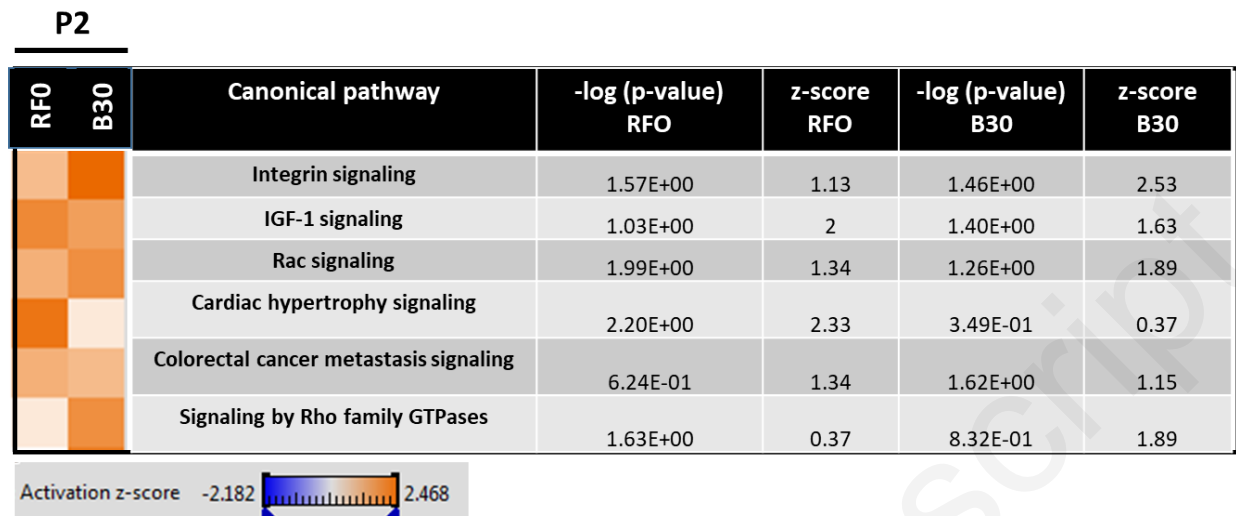
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692 **Figure 3 :**

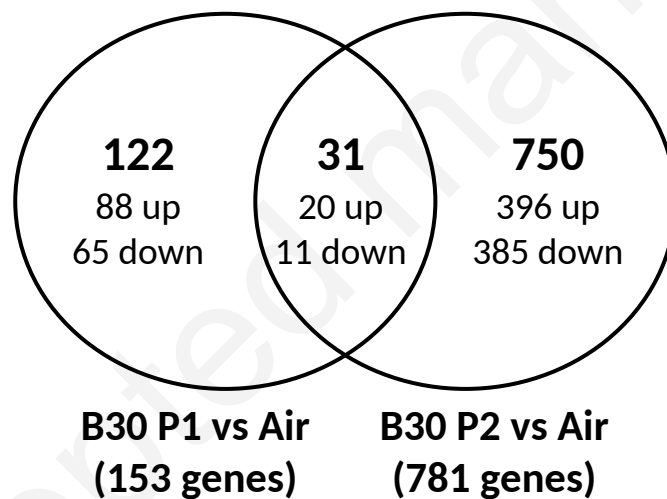


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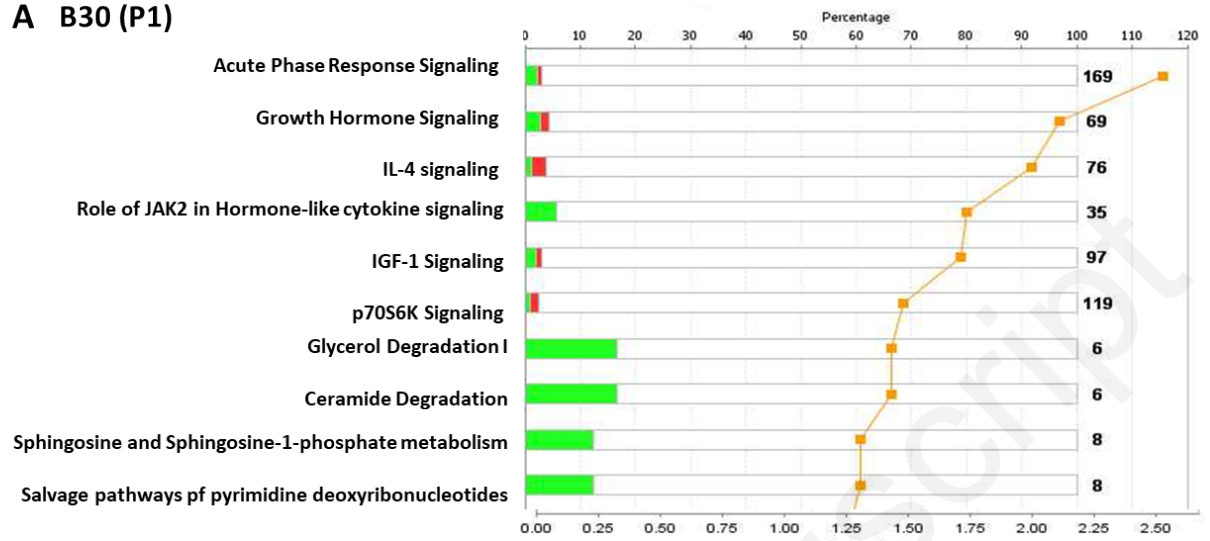
694 **Figure 4:**



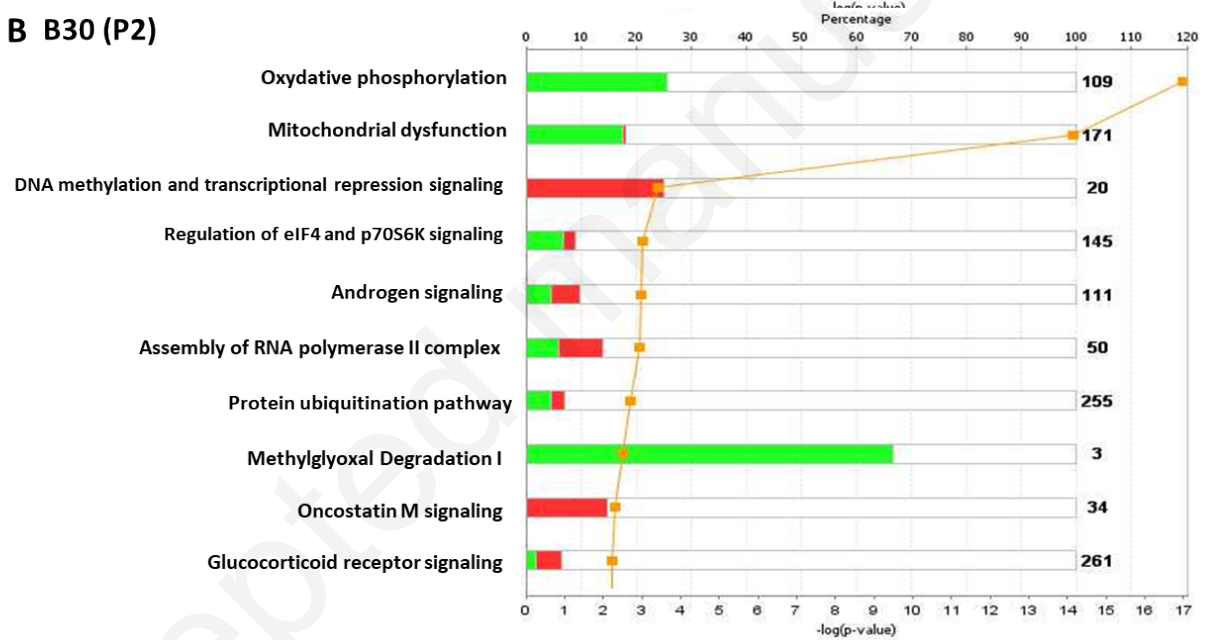
696 **Figure 5:**

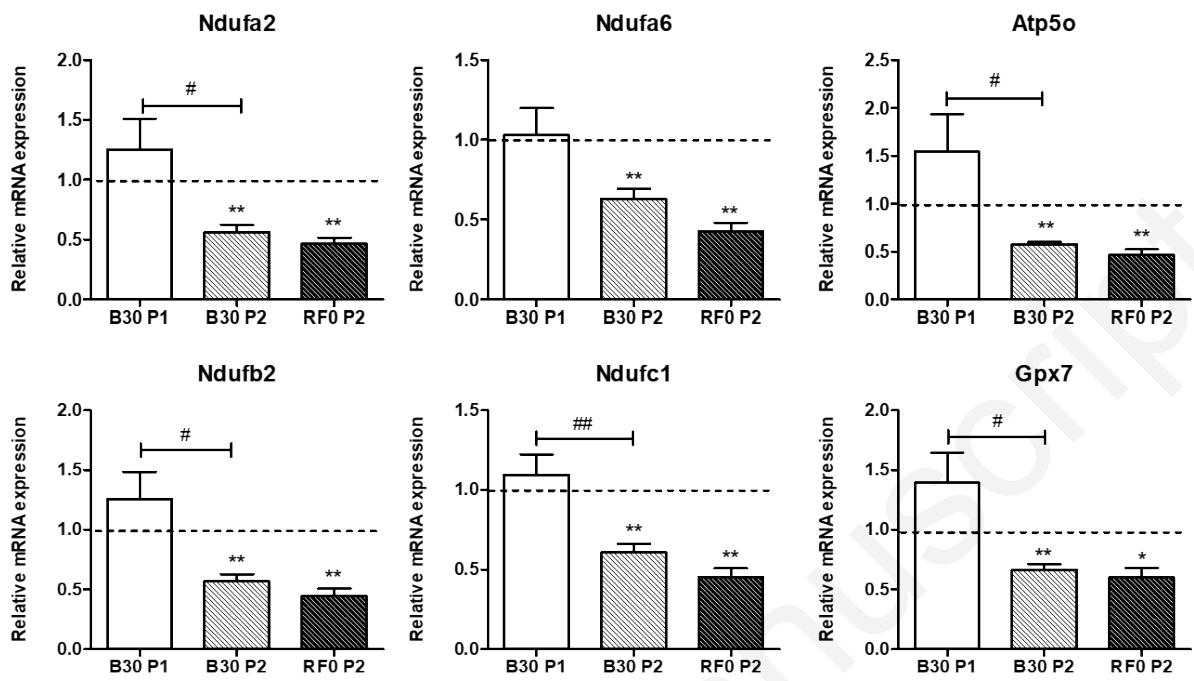


**A B30 (P1)**



**B B30 (P2)**







**Table 1** : BTEX (Benzene, Toluene, Ethylbenzene, Xylene), aldehydes, alkanes (from C8 to C40) and Polycyclic Aromatic Hydrocarbons (PAHs) concentrations in  $\mu\text{g}/\text{m}^3$  in samples from RF0 or B30 exhausts collected upstream of the diesel particle filter (DPF) (P1) or downstream the DPF (P2). Two measures were done for each exposure campaign.

Chemicals ( $\mu\text{g}/\text{m}^3$ )	Standard fuel (RF0)					Fuel mix (B30)				
	P1 measure	P1 measure	P2 measure	P2 measure	Range of Ratio P2/P1	P1 measure	P1 measure	P2 measure	P2 measure	Range of Ratio P2/P1
BTEX	45,8	53,6	4,17	7,80	<b>0,09-0,15</b>	82,2	218,9	24,2	124,7	<b>0,3-0,6</b>
aldehydes	37,3	44,2	182,9	194,3	<b>4,4-4,9</b>	13,5	36,1	14,2	11,3	<b>0,3-1,1</b>
alkanes (C8-C40)	124,3	341,5	438,3	133,9	<b>0,4-3,5</b>	368,0	177,8	63,9	66,4	<b>0,2-0,4</b>
PAHs	1,02	9,89	5,79	3,51	<b>0,4-5,7</b>	4,04	2,38	0,58	0,07	<b>0,03-0,14</b>

**Fig.1**

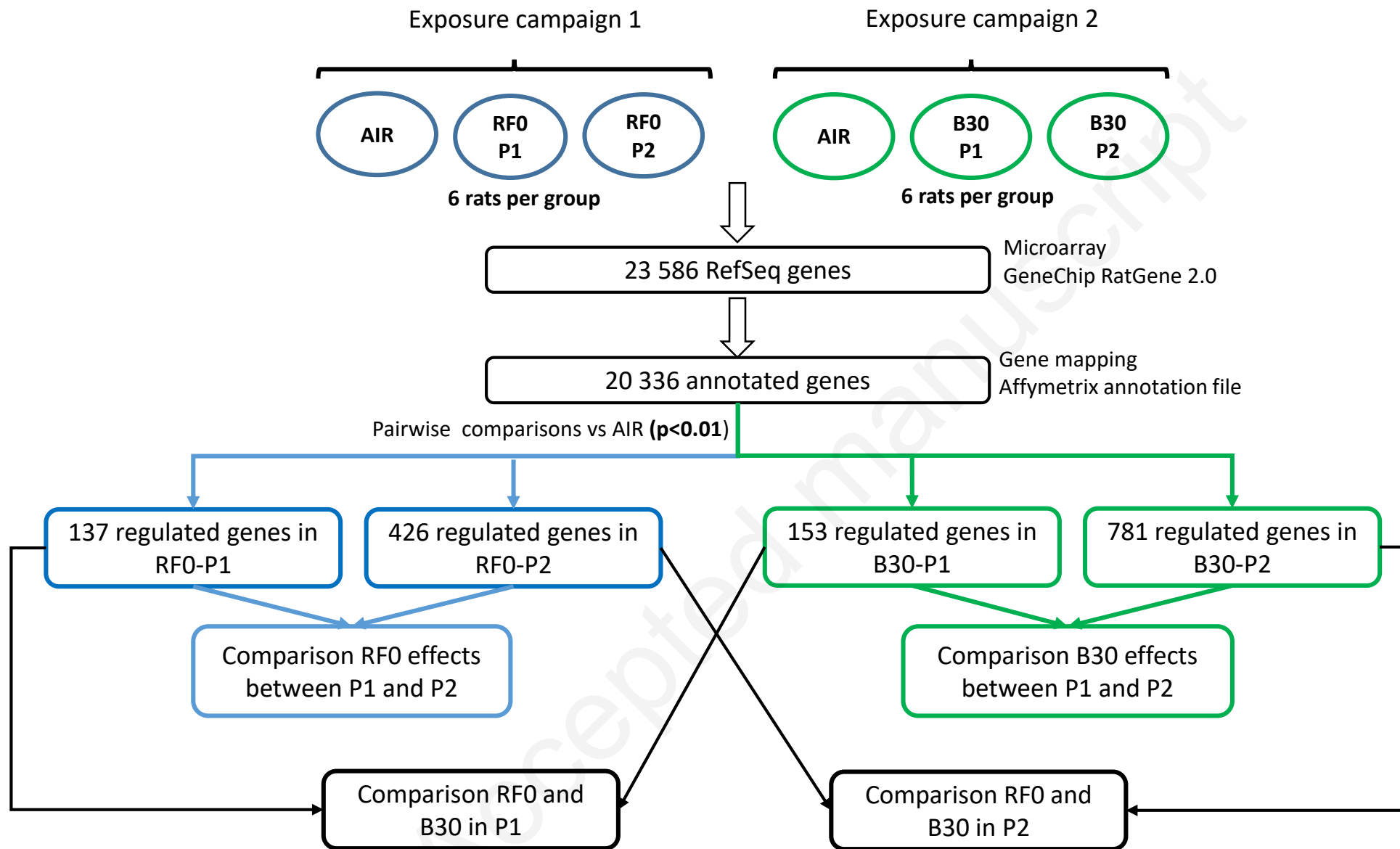
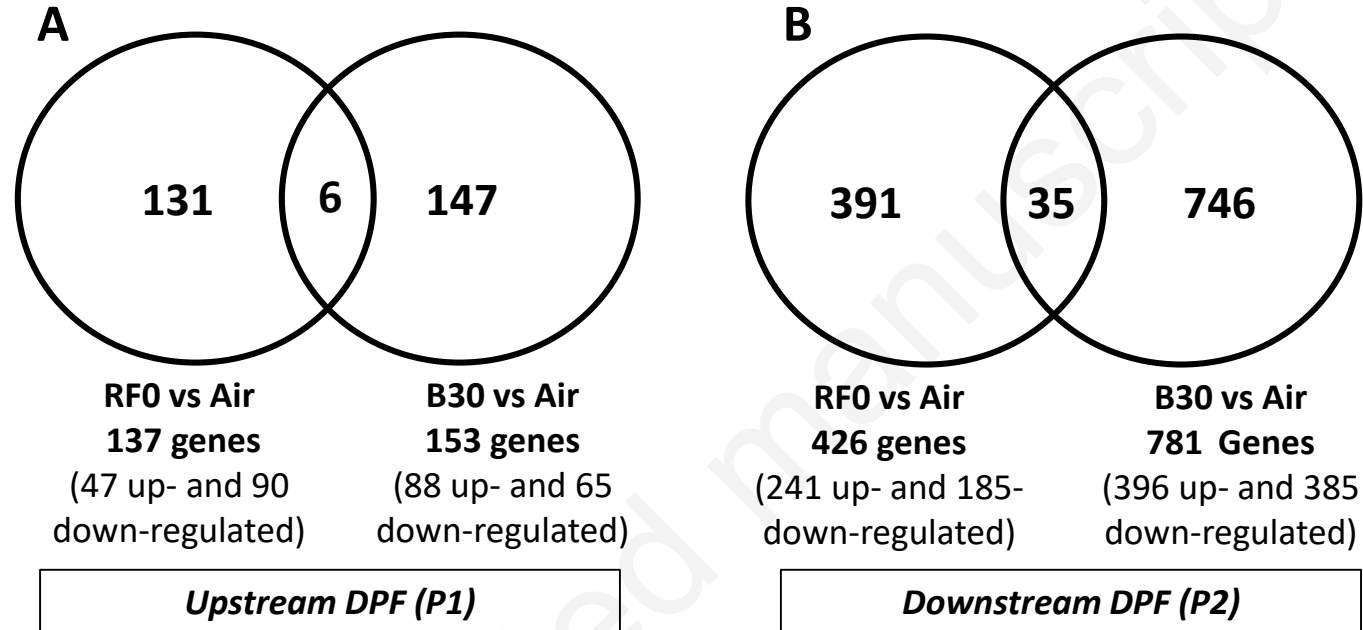


Fig.2



**Table 2: Top Network of B30 P2 (A) and RF0 P2 (B)**

<b>A</b>	<b>Top Diseases and Functions (B30 P2 versus air control)</b>	<b>Score</b>	<b>Diff expressed genes in pathway</b>
1	Cancer, Gene Expression, Cellular Development	45	33
2	Cellular Assembly and Organization, Cellular Function and Maintenance, Cell Death and Survival	34	28
3	Cellular Movement, Cell-To-Cell Signaling and Interaction, Hair and Skin Development and Function	34	27
4	Cell-To-Cell Signaling and Interaction, Tissue Development, Cellular Assembly and Organization	30	25
5	Tissue Morphology, Metabolic Disease, Cellular Development	30	26
<b>B</b>	<b>Top Diseases and Functions (RF0 P2 versus air control)</b>	<b>Score</b>	<b>Diff expressed genes in pathway</b>
1	Cellular Development, Nervous System Development and Function, Skeletal and Muscular System Development and Function	37	26
2	Cellular Assembly and Organization, Cellular Development, Cellular Growth and Proliferation	33	24
3	Cellular Assembly and Organization, Cellular Function and Maintenance, Protein Synthesis	31	23
4	Lipid Metabolism, Small Molecule Biochemistry, Developmental Disorder	27	21
5	Hematological System Development and Function, Inflammatory Response, Tissue Morphology	22	18

Fig.3

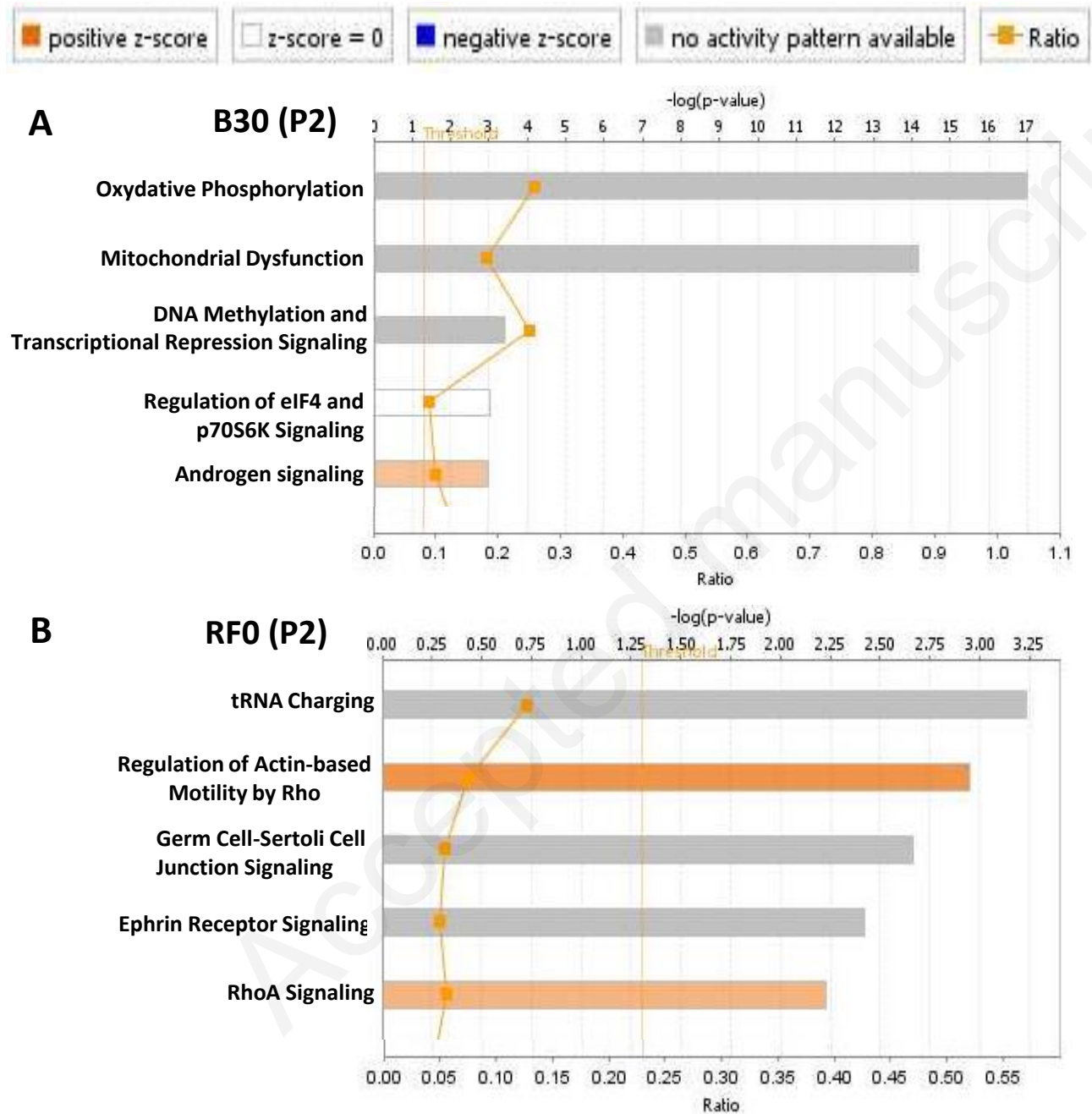



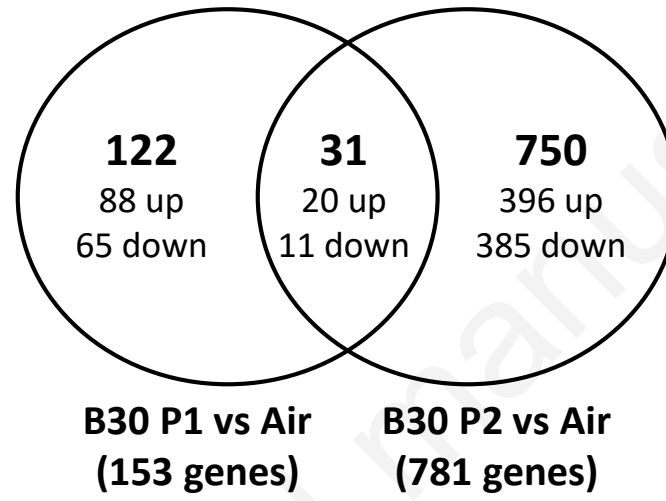
Fig.4

P2

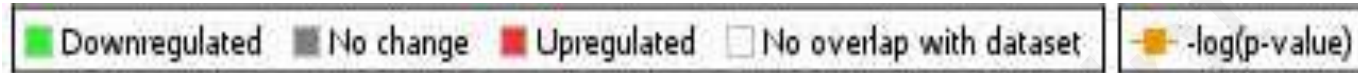
RFO	B30	Canonical pathway	$-\log(\text{p-value})$ RFO	z-score RFO	$-\log(\text{p-value})$ B30	z-score B30
		Integrin signaling	1.57E+00	1.13	1.46E+00	2.53
		IGF-1 signaling	1.03E+00	2	1.40E+00	1.63
		Rac signaling	1.99E+00	1.34	1.26E+00	1.89
		Cardiac hypertrophy signaling	2.20E+00	2.33	3.49E-01	0.37
		Colorectal cancer metastasis signaling	6.24E-01	1.34	1.62E+00	1.15
		Signaling by Rho family GTPases	1.63E+00	0.37	8.32E-01	1.89

Activation z-score -2.182  2.468

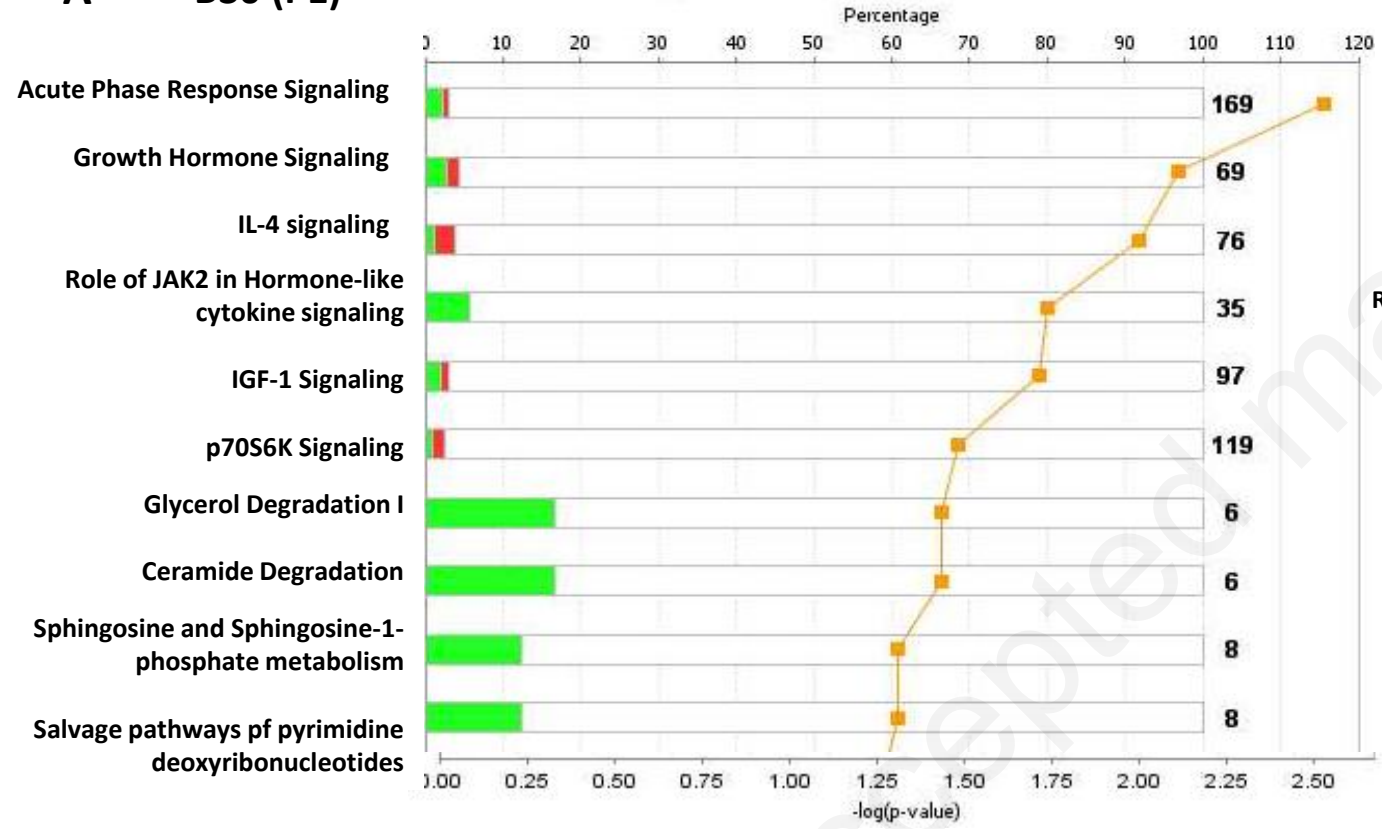
**Fig.5**



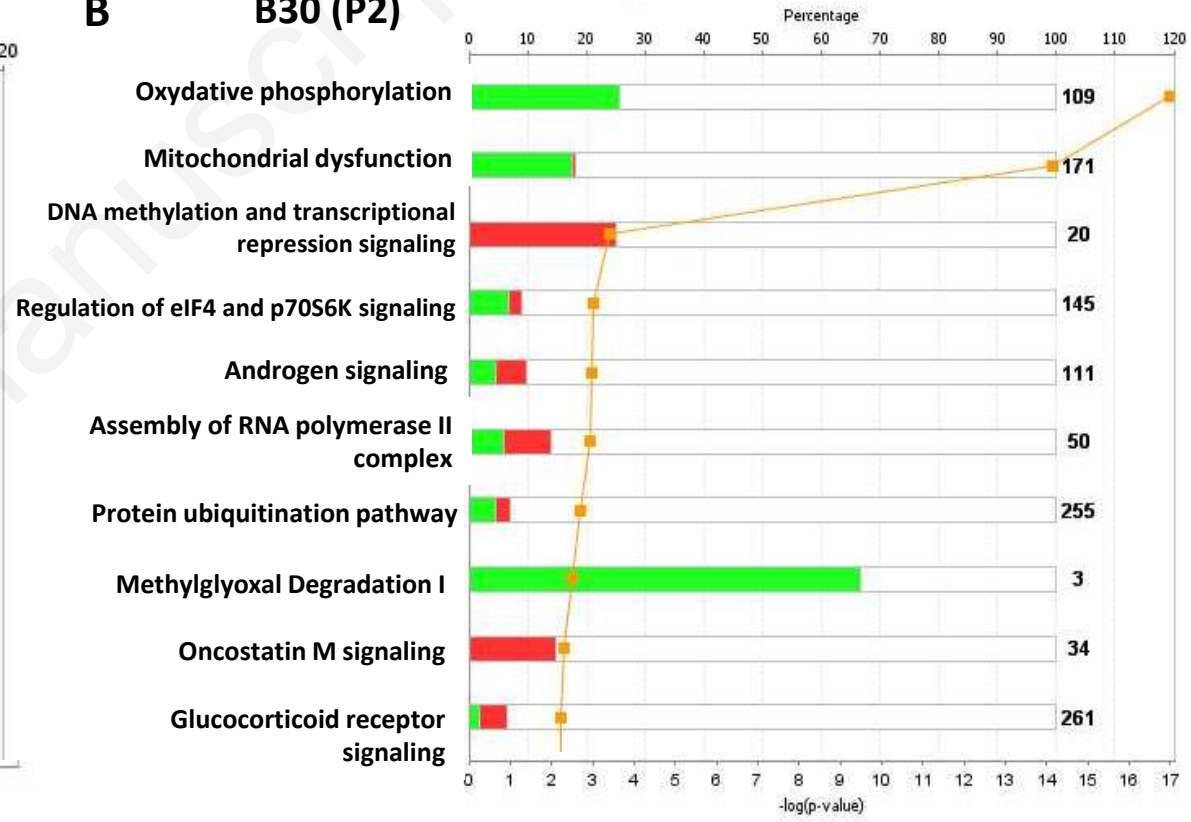
**Fig.6**



**A B30 (P1)**

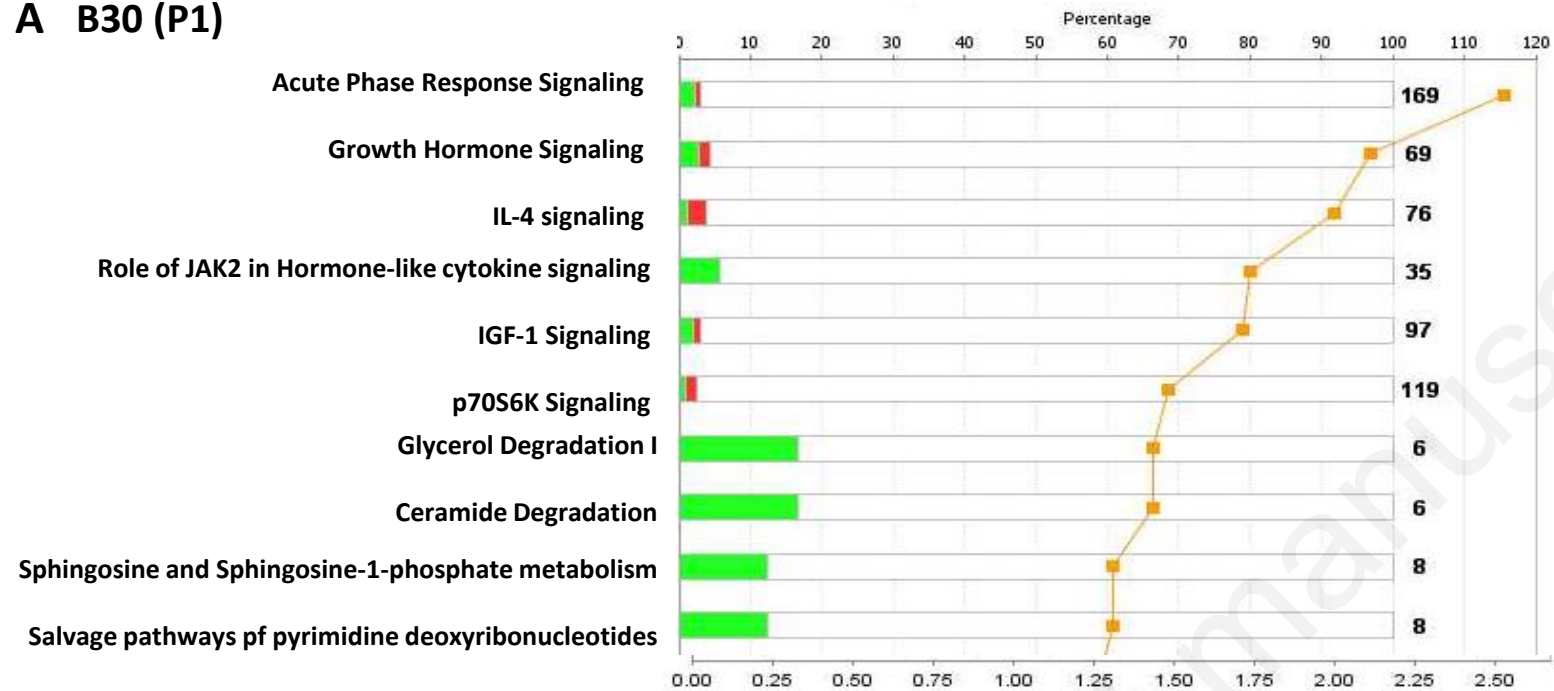


**B B30 (P2)**

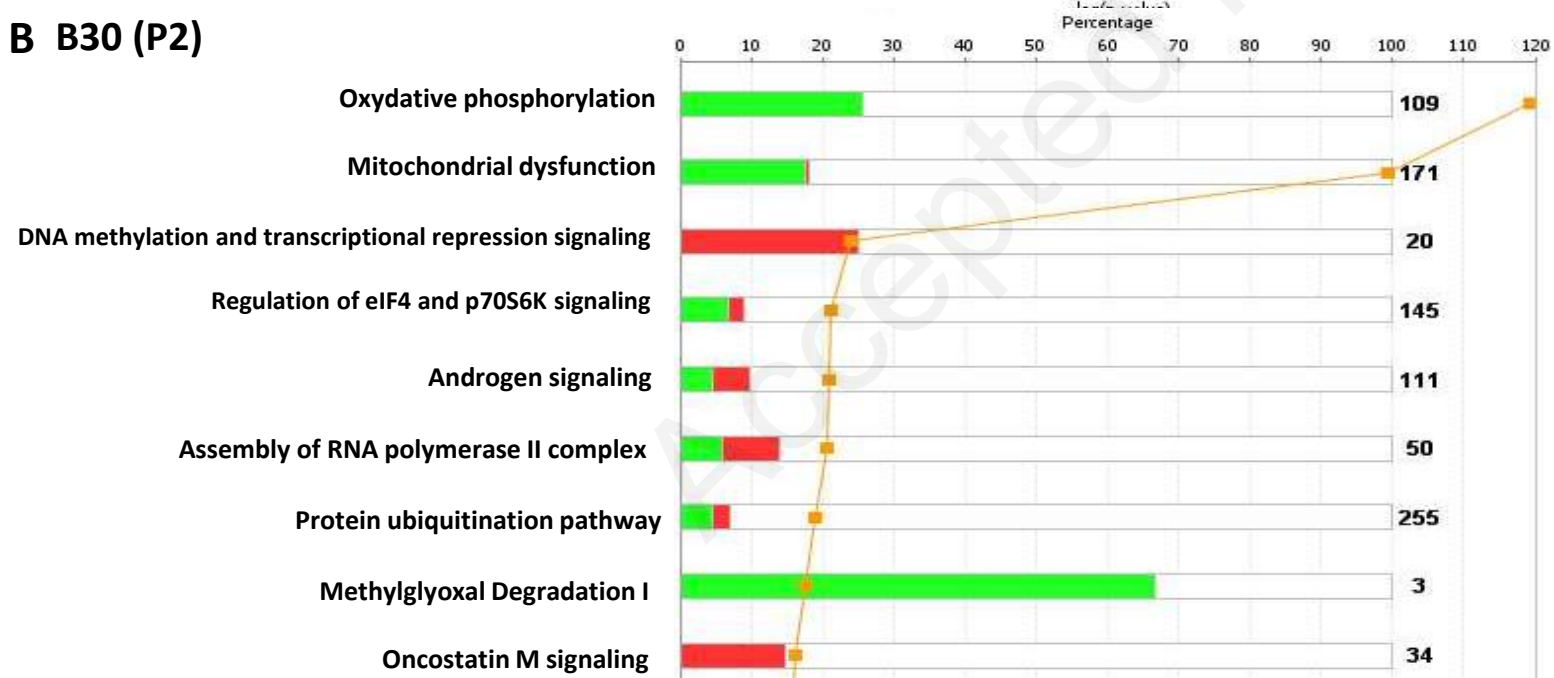




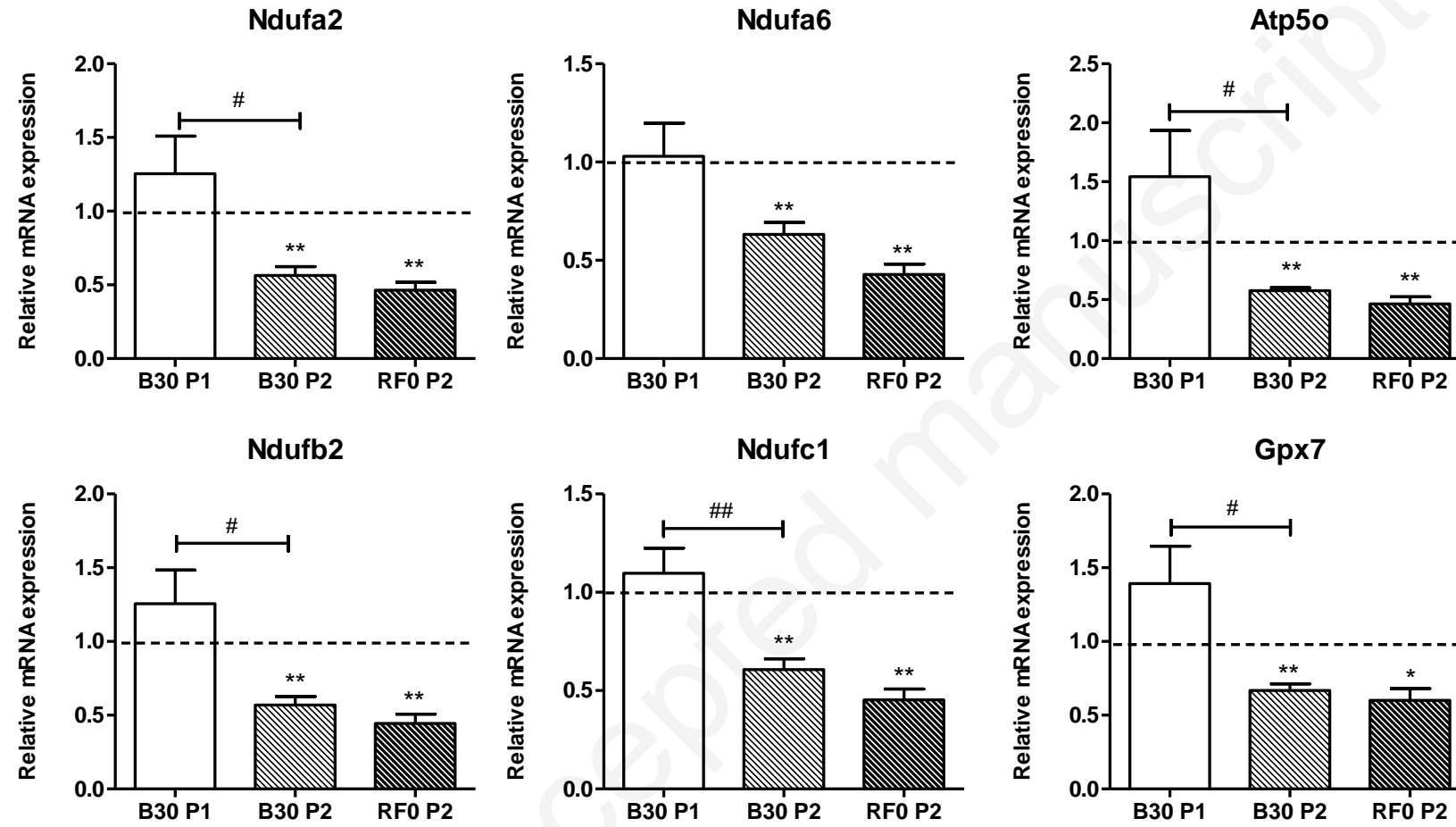
## A B30 (P1)



## B B30 (P2)



**Fig.7**



### Declaration of interests

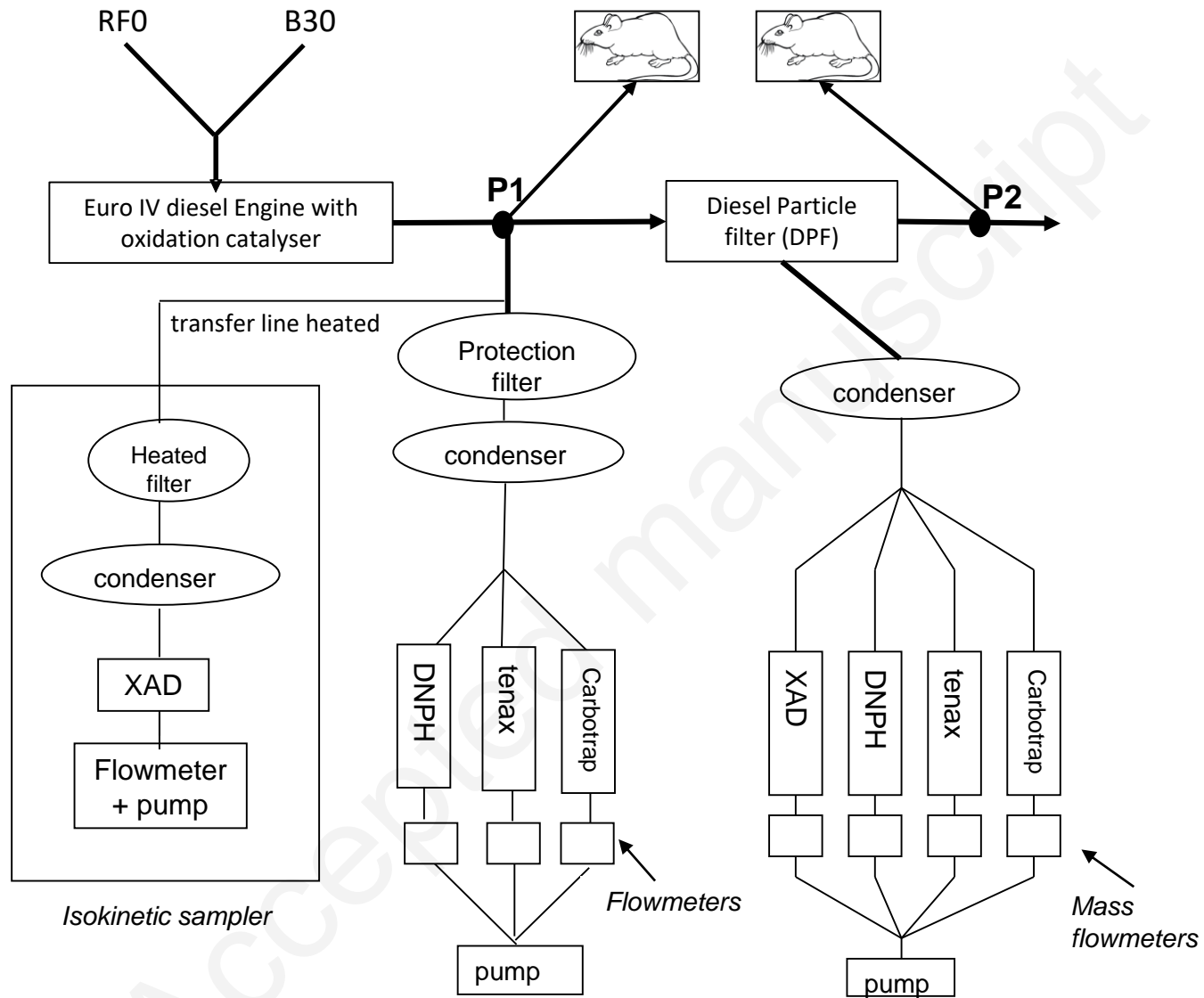
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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**Valérie Lecureur** : Conceptualization, Project administration, Data curation, Investigation, Formal analysis, writing. **Christelle Monteil** : Conceptualization, Project administration, Investigation, Formal analysis. **Marie Jaguin** : Methodology, Validation. **Fabrice Cazier** : Methodology, Investigation, Formal analysis. **David Preterre** : Conceptualization, Investigation. **Cécile Corbière** : Methodology, Investigation. **Pierre Gosset** : Methodology, Investigation, Formal analysis. **Thierry Douki** : Conceptualization, Project administration, Funding acquisition. **François Sichel** : Conceptualization, Project administration, Funding acquisition. **Olivier Fardel** : Project administration, Investigation, writing



**Figure S1:** Set-up for the exposure of animals to the exhausts of a diesel engine collected either upstream (P1) or downstream (P2) of the diesel particle filter (DPF) and for collection and measurements of exhausts.

**Table S1 : Gaseous pollutants concentrations and total PM mass concentration measured in the raw exhaust.** Gaseous pollutants monitored continuously in the exhaust emitted by a diesel engine used under driving cycles NEDC. The values indicate the mean of concentration measured during 9 NEDC cycles during 3h of exposure.

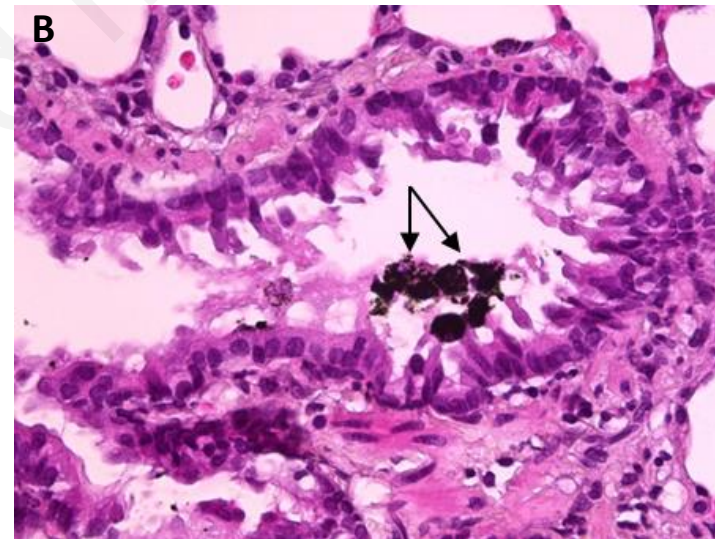
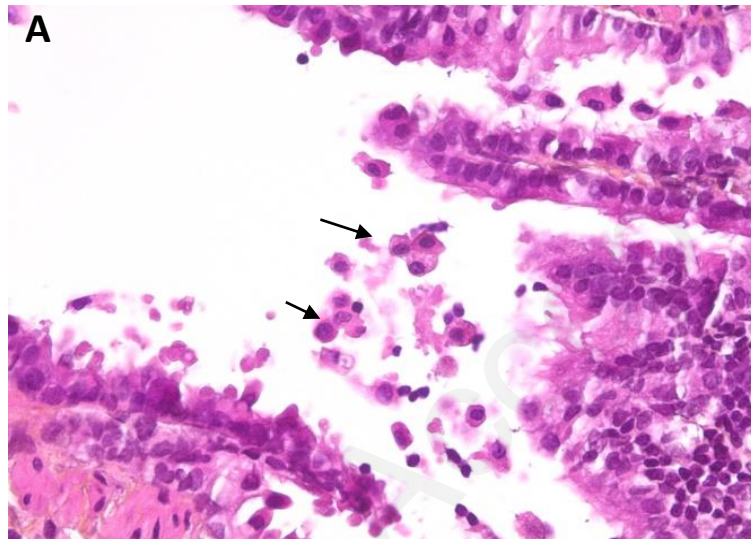
Gaseous pollutants concentrations	RFO		B30		B30/RFO	B30/RFO
	P1	P2	P1	P2	P1	P2
NO, ppmV	17	15	34	35	2	2,3
NOX, ppmV	30	28	83	82	2,8	2,9
Total gaseous hydrocarbons, ppmV	26	26	21	15	0,8	0,6
CO, ppmV	103	95	31	28	0,3	0,3
PM concentrations (mg/m <sup>3</sup> )	24	<0,1	23	<0,1	nd	nd

**Table S2** : Body weight of rats before and after 3 weeks (3h/day and 5 days/week) of exposure to Air, RFO or B30 exhausts, upstream (P1) or downstream (P2) to the particles filter (DPF). Data are the means  $\pm$  sem (n=6 per lots). The data in brackets represents the percentages of weight gain of the rats. \*: p<0.05 vs their respective Air control .

	weight basal	weight after 3 weeks		
		Air	P1	P2
<b>RFO</b>	299 $\pm$ 6	436 $\pm$ 14 (+ 45 %)	396 $\pm$ 17* (+ 31 %)	420 $\pm$ 11 (+ 43 %)
<b>B30</b>	269 $\pm$ 3	364 $\pm$ 15 (+ 37 %)	337 $\pm$ 12 (+28 %)	338 $\pm$ 9 (+ 30 %)

**Figure S2:** Histological analysis of rat lung tissues. The table shows the histological score of lung inflammation and the aspect of alveolar macrophages (pigmented or not). Staining of lung (left upper lobe) (x400) by HES of rat exposed to filtered air (A) or to RF0-P1 (B) showing non pigmented macrophages (A) and pigmented macrophages (B) (black arrow).

		Histological score of lung inflammation				Presence of pigmented macrophages in bronchi
		1 = No	2 = Mild	3 = moderate	4 =severe	
campaign 1- RF0	<b>Filtered Air (n=6)</b>	50%	50%	0%	0%	0%
	<b>RF0-P1 (n=6)</b>	66%	22%	22%	0%	100%
	<b>RF0-P2 (n=6)</b>	33%	17%	50%	0%	0%
campaign 2- B30	<b>Filtered Air (n=6)</b>	66%	34%	0%	0%	0%
	<b>B30-P1 (n=6)</b>	0%	50%	50%	0%	100%
	<b>B30-P2 (n=6)</b>	17%	50%	33%	0%	0%





**Table S5** : Comparison of mRNA expression variation (in fold) between transcriptomic array values and RT-qPCR data.

Fold expression	RF0 in P2		B30 in P2	
	Array	PCR	Array	PCR
RPS6KB1	1.1	0.8	1.11	0.85
PRKAR2A	1.33	0.87	1.21	1.05

**Table S6** : List of the canonical pathways regulated by B30 exhaust exposure in P2/DPF downstream condition, with **the** z-score. This list was obtained by sorting the forty first canonical pathways (classified in function of their p-values) by their z-score. In bold, canonical pathways also identified in RFO (P2).

<b>Canonical Pathways of B30 in P2 on the forty first pathway sorted first by the p-value and then by the z-score.</b>				
<b>Ingenuity Canonical Pathways</b>	<b>-log(p-value)</b>	<b>Ratio</b>	<b>z-score</b>	<b>Molecules</b>
<b>Integrin Signaling</b>	1.46E+00	5.94E-02	2.53	ROCK1,ARHGAP5,SRC,ITGA3,ARF5,Ppp1r12a,RHOC,ITGA6,TLN1,ACTN4,PDGFB,ACTN1
Oncostatin M Signaling	2.33E+00	1.47E-01	2.23	TIMP3,JAK1,STAT3,PLAU,STAT5B
VEGF Signaling	1.53E+00	7.69E-02	2.23	ROCK1,EIF2S2,SRC,HIF1A,ACTN4,ACTN1,EIF1AX
EGF Signaling	1.44E+00	8.93E-02	2.23	RPS6KB1,SRC,JAK1,JUN,STAT3
Remodeling of Epithelial Adherens Junctions	1.62E+00	8.82E-02	2	SRC,CDH1,ACTN4,IQGAP1,ACTN1,CTNND1
<b>Rac Signaling</b>	1.26E+00	6.73E-02	1.89	RPS6KB1,ITGA3,JUN,CYFIP1,NCF2,PIP4K2B,IQGAP1
<b>IGF-1 Signaling</b>	1.40E+00	7.22E-02	1.63	RPS6KB1,JAK1,JUN,CTGF,PRKAR2A,STAT3,PRKAG1
PCP pathway	1.26E+00	7.94E-02	1.34	ROCK1,JUN,FZD4,WNT10A,FZD6
Leukocyte Extravasation Signaling	1.52E+00	6.06E-02	1.26	ROCK1,ARHGAP5,SRC,TIMP3,ITGA3,CYBA,NCF2,ITGA6,RASSF5,ACTN4,ACTN1,CTNND1
Colorectal Cancer Metastasis Signaling	1.62E+00	5.93E-02	1.15	SRC,JAK1,RHOC,GNB2L1,PRKAR2A,STAT3,PRKAG1,CDH1,JUN,FZD4,MSH2,WNT10A,FZD6,RALGDS
Androgen Signaling	2.98E+00	9.91E-02	1	POLR2G,SRC,CCNH,POLR2A,JUN,GNB2L1,PRKAR2A,GTF2E2,GTF2F1,GTF2A1,PRKAG1
mTOR Signaling	2.06E+00	6.95E-02	0.44	RPS6KB1,RPS4Y1,EIF3F,FAU,RPS16,RHOC,RPS27L,EIF3A,HIF1A,RPS5,EIF4E,PRKAG1,RPSA