Data Analysis 2

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If we want an abstract it will go here. References are in the form Astley (1987) or (Astley 1987). For more information see here.

Introduction

Our clients conducted an experiment to determine the effect pine tissues, precipitation levels, time, and the interaction of these variables effects starch content. In total, 408 entries were recorded. The experiment was replicated at two locations as well and not all measurements within each replication were taken from the same sample location. (dont like that last line)

We intend to analysis the results of this data below. We will review the variables, fit multiple models, and make a suggestion to the client. The data set, `data.csv`, and all other files used in this project can be found on our Github page.

Exploring the Data

Variables

In the data set provided by the client there are four tissue types which are abbreviated as END, IT, LM, and UM. This can be found in the `tissu` column. The two precipitation levels, control and drought, are in the `treatment` column. The time component of the experiment is not simply one variable. The `time` column consists of six different times, with six being denoted by the first six letters of the alphabet. In addition to `time`, the column `dayPeriod` indicates whether the measurement was taken in the day or at night. Time points C and D appear to correspond to a `dayPeriod` of night, while all other time points are during the day. Note, the measurements for the starch contents can be found in the `StarchNscTissue` and each sample number can be found in the `sample` column.

The data set provided by the client also includes variables that indicate the physical location of where the measurement was taken within a sample. These are represented the columns `row`, `col`, and `chamber` with the latter being in the form `row-col` for each respective entry. The possible values of `row` and `col` range from one to four. Also, since the experiment was carried out at two locations which is represented by the `campagne` column.

Changes made to the variables in the original data set

Note there were a couple of problems with the original data set. Initially the `time` column included a seventh time, A'. Since this did not follow the format of the other time points and had substantially fewer occurrences in the data, we assumed this was a mistake. Therefore, we manually changed all occurrences of A' to A.

The other potential issue was in the `chamber` column. As stated above this column should be a combination of `row` and `col`, but the original data set was treating it as a date. For example if one sample has the values `row` $= 1$ and `col` $= 4$, the result of `chamber` should be $1 - 4$. Instead the original data set was showing January 4th. We chose to manually change this to the correct format as well.

Summary Statistics

While some of the variables outlined above are numeric, most can be treated as categorical. The lone exception to this is the starch content. The table below shows some summary statistics for the starch content. This includes not only the summaries of all 408 measurements, but also the summaries based on the two values of `campagne` and `dayPeriod`.

Group	N	Mean	Median	SD	Min	Max
Overall	408	1.924902	1.429527	1.733284	0.0191182	7.898429
campagne: 1	184	1.340544	1.245685	1.008316	0.0191182	6.480553
campagne: 2	224	2.404911	1.677605	2.033619	0.2029488	7.898429
dayPeriod: Day	280	1.895429	1.357646	1.730086	0.0191182	7.898429
dayPeriod: Night	128	1.989375	1.483575	1.745326	0.0656625	7.537576

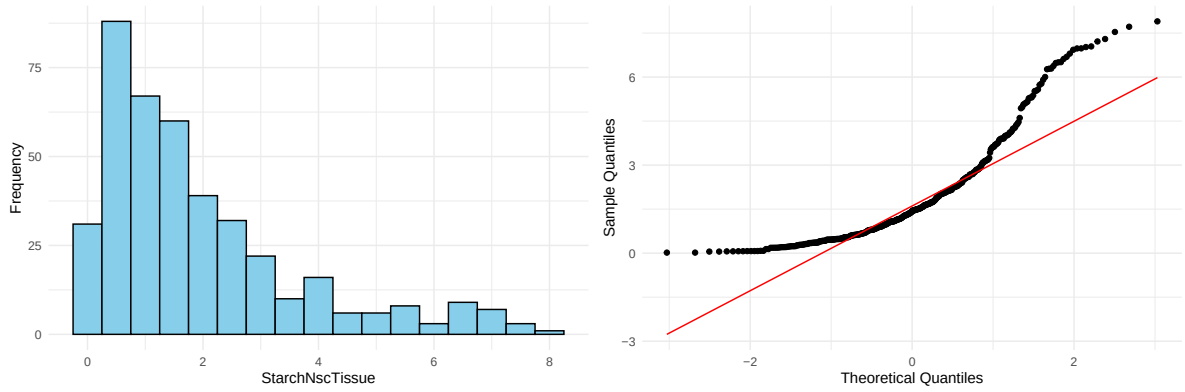
Figure 1: Summary statistics of starch content.

For starch contents across all measurements, the values range from about 0.019 to 7.898 with a median of roughly 1.430 and a mean of 1.925. The location of the median and mean with respect to the minimum and maximum is an early sign that the starch contents could be skewed and thus non-normal in distribution.

When comparing the two locations (`campagne`) where the experiment was replicated, we can see the 184 measurements from the first location seems to have lower values on average than the 224 measurements from location 2. There is a smaller difference in these metrics when comparing measurements taken in the day versus those taken in the night. Note over twice as many measurements were taken in the day.

To generate a table of summary statistics that account for more of the variables see *Appendix A - R Code*. That table is not included here due to its larger size.

As previously noted, the table above indicates the starch contents may be skewed and thus non-normal. This can be evaluated through a histogram and Q-Q plot. The histogram below supports our suspicion that the data is skewed and the Q-Q plot confirms the measure is non-normal. Note, all 408 measurements of starch content are used in the plots.



(a) Histogram of starch content.

(b) Q-Q plot of starch content.

Figure 2: Plots used to check normallity assumption.

Relationships among variables

Potential models

The replication mentioned above suggests a mixed model approach is needed. This is due to the replication being a random effect. The simplest case of a this type of model is a linear mixed model. To use this, the residuals of the model must be approximately normally distributed.

How explanatory variables can be used

(talk about nesting vs non-nesting methods I guess. Just introduce the idea before we actually make the models.)

Summary Statistics and other graphs

Summary_Statistic

```
# A tibble: 48 x 10
# Groups:   tissu, treatment, dayPeriod [16]
   tissu treatment dayPeriod time  mean_Starch sd_Starch median_Starch
   <chr> <chr>     <chr>     <chr>       <dbl>     <dbl>         <dbl>
 1 END   Control   Day       A           0.800     0.427         0.766
 2 END   Control   Day       B           0.806     0.468         0.965
 3 END   Control   Day       E           0.736     0.598         0.562
 4 END   Control   Day       F           0.740     0.178         0.765
 5 END   Control   Night     C           0.824     0.478         1.03
 6 END   Control   Night     D           0.700     0.381         0.714
 7 END   Drought   Day       A           0.507     0.110         0.481
 8 END   Drought   Day       B           0.870     0.468         0.622
 9 END   Drought   Day       E           0.765     0.408         0.687
10 END   Drought   Day       F           0.449     0.157         0.479
# i 38 more rows
# i 3 more variables: min_Starch <dbl>, max_Starch <dbl>, n <int>
```

Model - Mixed Effects Model with Interactions

```
/* Mixed Model*/
proc mixed data=data method=reml plots=(residualpanel);
    class treatment tissu dayPeriod campagne chamber;
    model StarchNscTissue = treatment|tissu|dayPeriod;
    lsmeans treatment dayPeriod tissu / pdiff=all cl adjust=tukey;
    random campagne chamber sample;
run;
```

Output

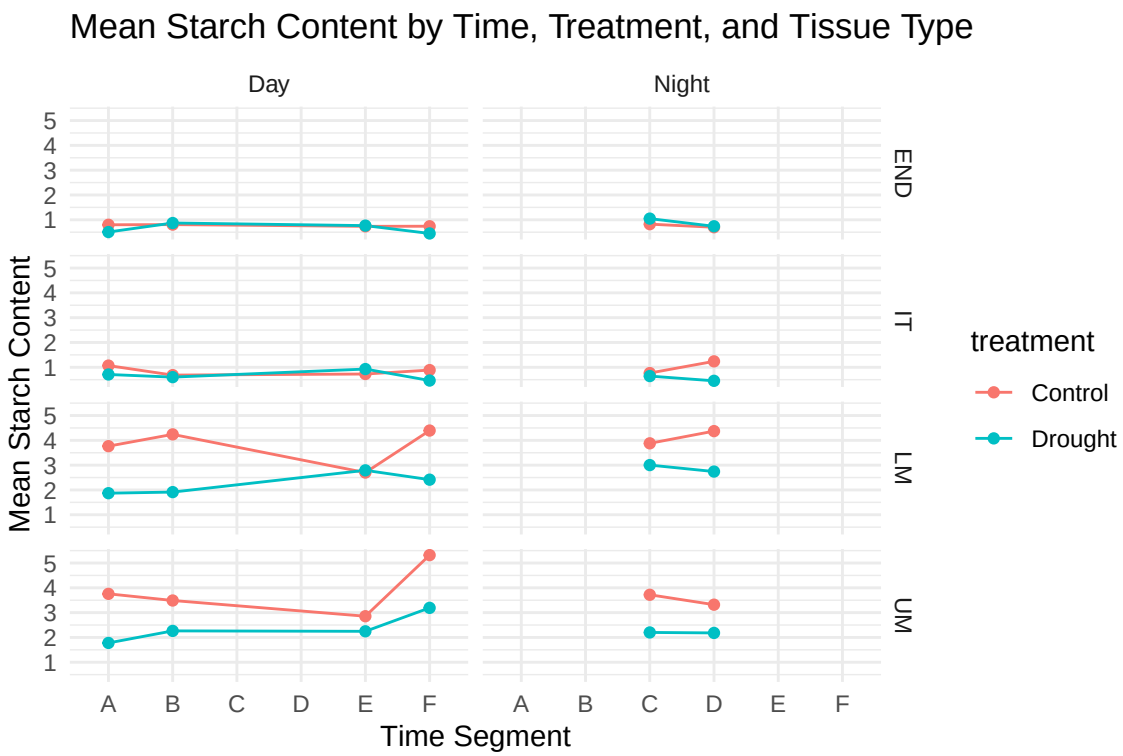

Mean Starch Content by Time, Treatment, and Tissue Type
Day
Night
END
IT
LM
UM
Mean Starch Content
Time Segment
A
B
C
D
E
F
1
2
3
4
5
treatment
Control
Drought

Figure 3: jjj

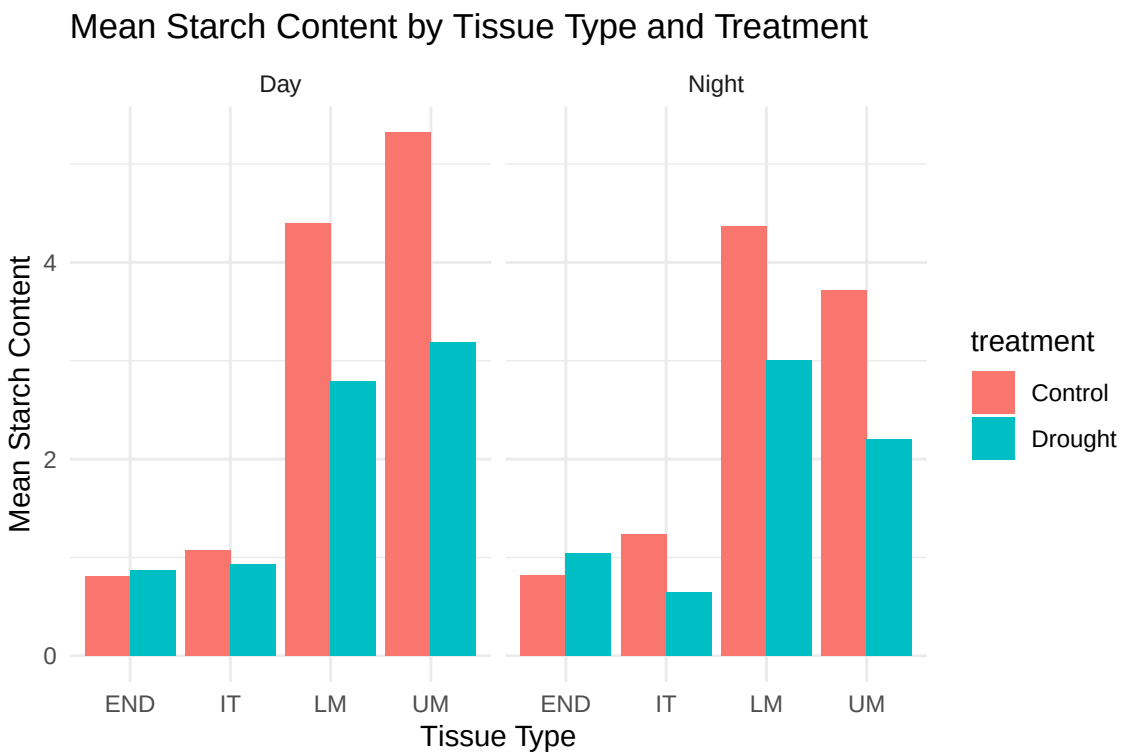

Mean Starch Content by Tissue Type and Treatment
Day
Night
Mean Starch Content
0
2
4
END
IT
LM
UM
Tissue Type
treatment
Control
Drought

Figure 4: jjj

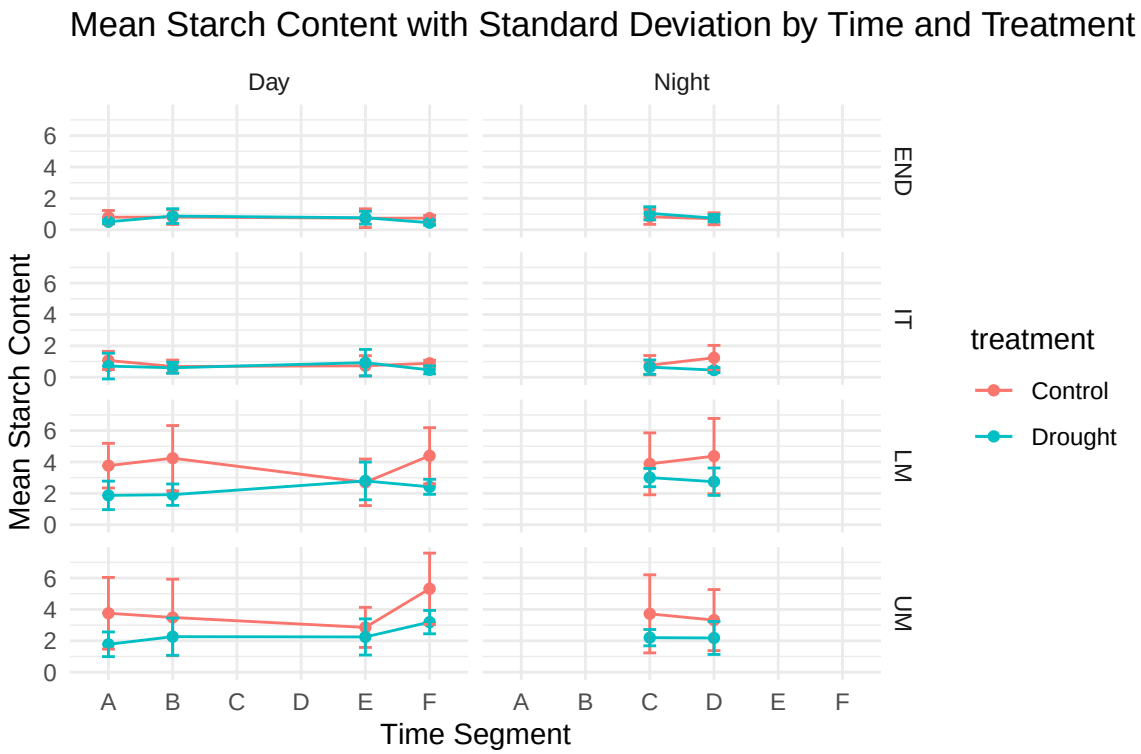

Mean Starch Content with Standard Deviation by Time and Treatment
Day
Night
END
IT
LM
UM
Mean Starch Content
Time Segment
A
B
C
D
E
F
0
2
4
6
treatment
Control
Drought

Figure 5: jjj

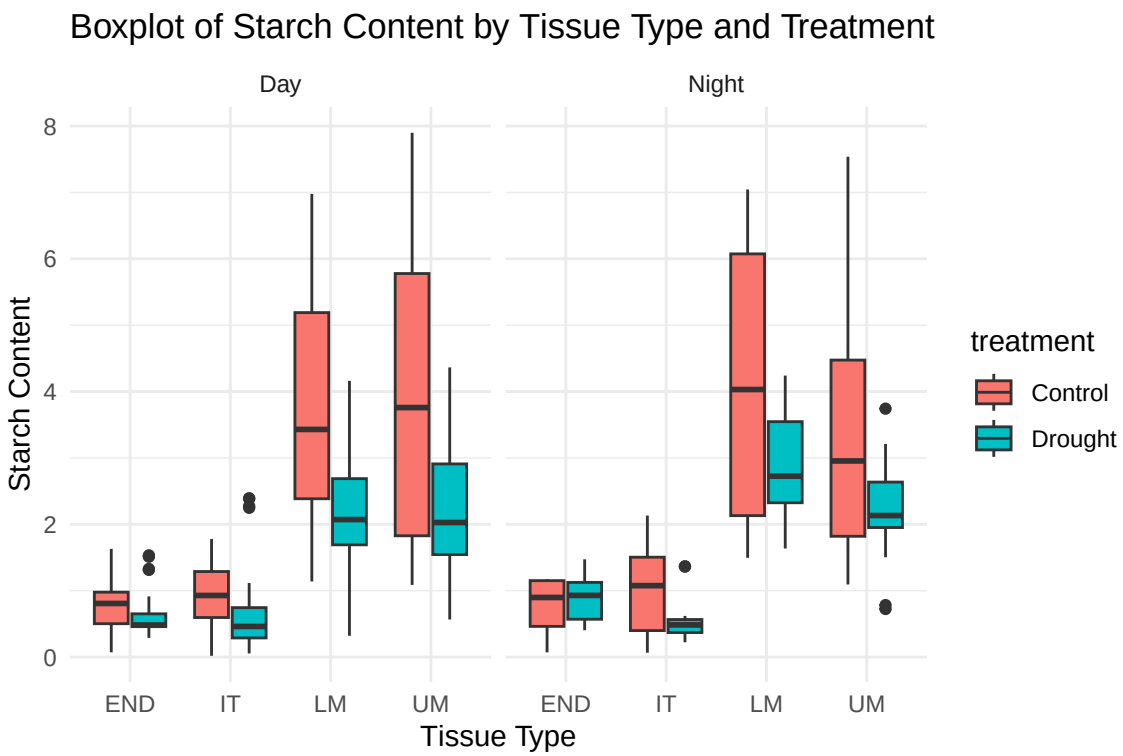

Boxplot of Starch Content by Tissue Type and Treatment
Day
Night
Starch Content
0
2
4
6
8
END
IT
LM
UM
Tissue Type
treatment
Control
Drought

Figure 6: jjj

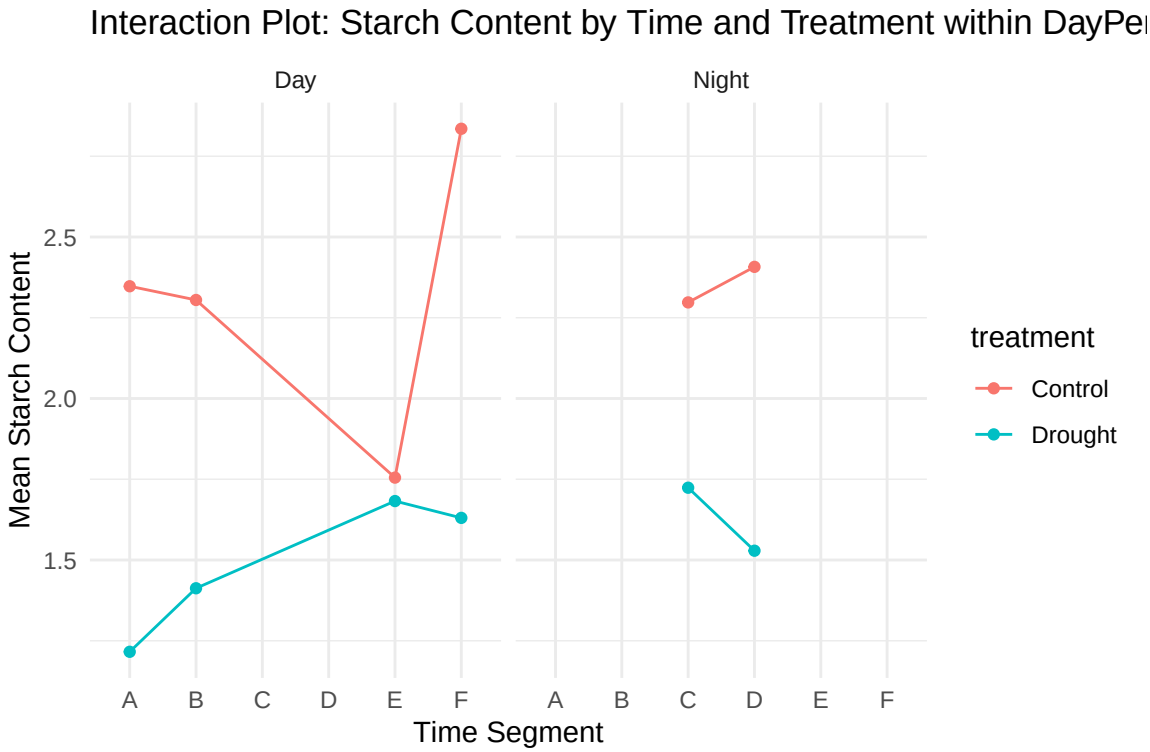

Interaction Plot: Starch Content by Time and Treatment within DayPe
Day
Night
Mean Starch Content
2.5
2.0
1.5
A
B
C
D
E
F
Time Segment
treatment
Control
Drought

Figure 7: jjj

Estimated G matrix is not positive definite.

Covariance Parameter Estimates	
Cov Parm	Estimate
campagne	1.75E-18
chamber	0.1694
sample	4.898E-6
Residual	0.9277

Fit Statistics	
-2 Res Log Likelihood	1150.3
AIC (Smaller is Better)	1156.3
AICC (Smaller is Better)	1156.3
BIC (Smaller is Better)	1152.4

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
treatment	1	386	6.26	0.0128
tissu	3	386	172.71	<.0001
treatment*tissu	3	386	13.06	<.0001
dayPeriod	1	386	2.94	0.0874
treatment*dayPeriod	1	386	0.18	0.6731
tissu*dayPeriod	3	386	2.14	0.0950
treatm*tissu*dayPeri	3	386	0.45	0.7153

Figure 8: Fig-1

Interpretation In this model, we include interactions between tissu, treatment, and dayPeriod to evaluate their combined effects on StarchNscTissue.

- Treatment and tissue type have significant effects on starch content, with tissue type having the strongest effect.
- The interaction between treatment and tissue is also significant, indicating that the impact of treatment on starch content depends on the type of tissue.

- DayPeriod shows a weak effect, and interactions involving dayPeriod are not significant at the 5% level.

These results suggest that the model effectively captures differences in starch content across treatments and tissue types, with some minor time-of-day effects. Further exploration could involve focusing on treatment and tissue type differences, as well as investigating any practical relevance of the marginal effects of dayPeriod.

Least Squares Means

Effect	treatment	tissu	dayPeriod	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
treatment	Control			1.3348	0.3383	386	3.95	<.0001	0.05	0.6698	1.9999
treatment	Drought			0.5624	0.3394	386	1.66	0.0983	0.05	-0.1048	1.2297
dayPeriod			Day	0.8603	0.3036	386	2.83	0.0048	0.05	0.2634	1.4573
dayPeriod			Night	1.0369	0.3083	386	3.36	0.0008	0.05	0.4308	1.6431
tissu		END		-0.2229	0.3145	386	-0.71	0.4788	0.05	-0.8412	0.3954
tissu		IT		-0.2106	0.3145	386	-0.67	0.5035	0.05	-0.8288	0.4077
tissu		LM		2.2571	0.3145	386	7.18	<.0001	0.05	1.6389	2.8754
tissu		UM		1.9708	0.3145	386	6.27	<.0001	0.05	1.3526	2.5891

Figure 9: Fig-2

Interpretation

Differences of Least Squares Means

Effect	treatment	tissu	dayPeriod	_treatment	_tissu	_dayPeriod	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P	Alpha	Lower	Upper	Adj Lower	Adj Upper
treatment	Control			Drought			0.7724	0.3088	386	2.50	0.0128	Tukey-Kramer	0.0128	0.05	0.1654	1.3795	0.1654	1.3795
dayPeriod			Day			Night	-0.1766	0.1031	386	-1.71	0.0874	Tukey-Kramer	0.0874	0.05	-0.3793	0.02603	-0.3793	0.02603
tissu		END			IT		-0.01234	0.1454	386	-0.08	0.9324	Tukey-Kramer	0.9998	0.05	-0.2981	0.2734	-0.3874	0.3627
tissu		END			LM		-2.4800	0.1454	386	-17.06	<.0001	Tukey-Kramer	<.0001	0.05	-2.7658	-2.1943	-2.8551	-2.1050
tissu		END			UM		-2.1938	0.1454	386	-15.09	<.0001	Tukey-Kramer	<.0001	0.05	-2.4795	-1.9080	-2.5688	-1.8187
tissu		IT			LM		-2.4677	0.1454	386	-16.98	<.0001	Tukey-Kramer	<.0001	0.05	-2.7535	-2.1819	-2.8427	-2.0927
tissu		IT			UM		-2.1814	0.1454	386	-15.01	<.0001	Tukey-Kramer	<.0001	0.05	-2.4672	-1.8956	-2.5565	-1.8064
tissu		LM			UM		0.2863	0.1454	386	1.97	0.0496	Tukey-Kramer	0.2013	0.05	0.000504	0.5721	-0.08876	0.6613

Figure 10: Fig-3

Interpretation

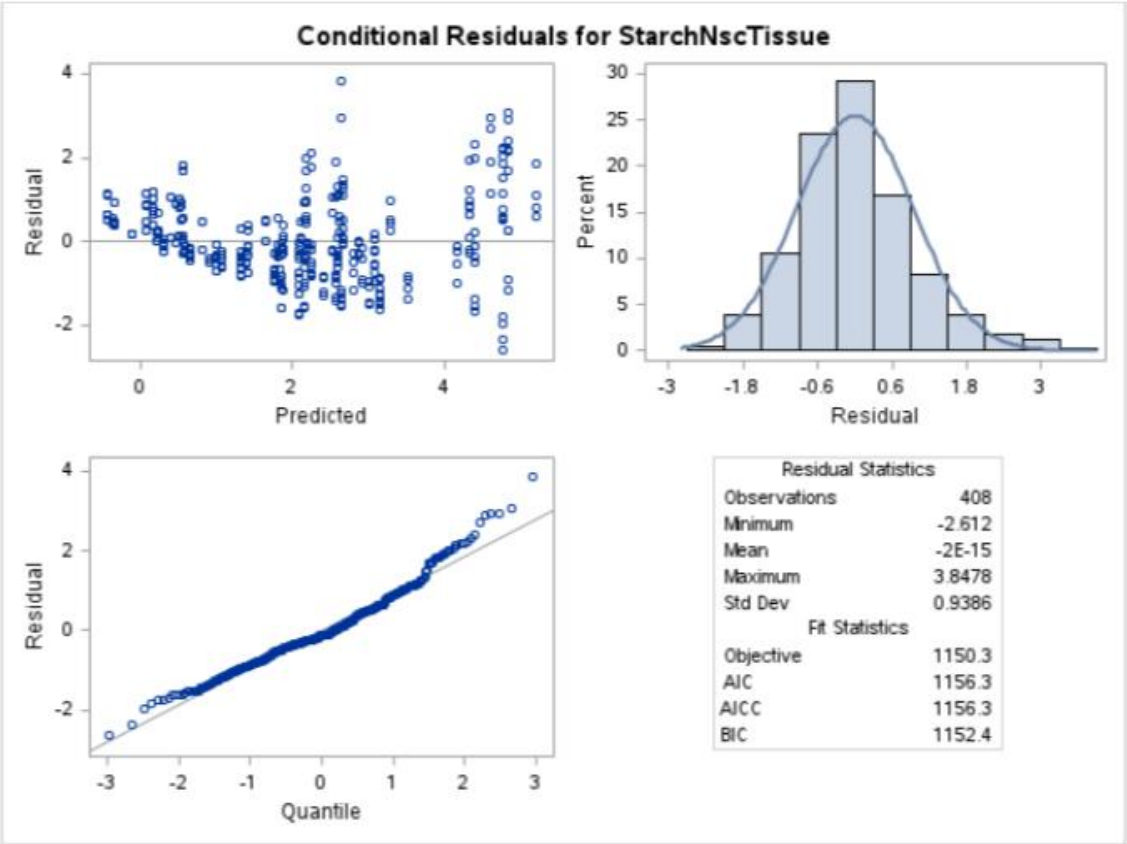


Figure 11: Fig-4

Interpretation

Split Plot Model

```
/* Split Plot*/
proc mixed data=data plots=(residualpanel);
    class campagne treatment chamber dayPeriod tissu;
    model StarchNscTissue = treatment | dayPeriod | tissu / ddfm=kr;
    random sample campagne chamber(campagne) dayPeriod*chamber(campagne);
    lsmeans treatment dayPeriod tissu / pdiff=all cl adjust=tukey;
run;
```

Output

Estimated G matrix is not positive definite.

Covariance Parameter Estimates	
Cov Parm	Estimate
sample	5.021E-6
campagne	0
chamber(campagne)	0.1691
chamb*dayPer(campag)	0.009976
Residual	0.9239

Fit Statistics	
-2 Res Log Likelihood	1150.1
AIC (Smaller is Better)	1158.1
AICC (Smaller is Better)	1158.2
BIC (Smaller is Better)	1150.1

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
treatment	1	5.07	6.13	0.0554
dayPeriod	1	6.07	2.37	0.1742
treatment*dayPeriod	1	6.06	0.15	0.7086
tissu	3	379	173.42	<.0001
treatment*tissu	3	379	13.11	<.0001
dayPeriod*tissu	3	379	2.15	0.0939
treatm*dayPeri*tissu	3	379	0.45	0.7140

Interpretation

Least Squares Means											
Effect	treatment	dayPeriod	tissu	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
treatment	Control			1.3231	0.3768	5.43	3.51	0.0149	0.05	0.3774	2.2688
treatment	Drought			0.5493	0.3781	5.47	1.45	0.2011	0.05	-0.3979	1.4966
dayPeriod		Day		0.8482	0.3464	5.72	2.45	0.0519	0.05	-0.00968	1.7060
dayPeriod		Night		1.0243	0.3503	6.06	2.92	0.0262	0.05	0.1693	1.8793
tissu			END	-0.2353	0.3549	6.52	-0.66	0.5300	0.05	-1.0872	0.6166
tissu			IT	-0.2230	0.3549	6.52	-0.63	0.5512	0.05	-1.0749	0.6289
tissu			LM	2.2447	0.3549	6.52	6.33	0.0005	0.05	1.3928	3.0966
tissu			UM	1.9584	0.3549	6.52	5.52	0.0011	0.05	1.1065	2.8104

Interpretation

Differences of Least Squares Means																		
Effect	treatment	dayPeriod	tissu	_treatment	_dayPeriod	_tissu	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P	Alpha	Lower	Upper	Adj Lower	Adj Upper
treatment	Control			Drought			0.7738	0.3125	5.07	2.48	0.0554	Tukey-Kramer	0.0554	0.05	-0.02607	1.5737	-0.02605	1.5736
dayPeriod		Day			Night		-0.1761	0.1145	6.07	-1.54	0.1742	Tukey-Kramer	0.1742	0.05	-0.4555	0.1032	-0.4555	0.1032
tissu			END			IT	-0.01234	0.1451	379	-0.09	0.9322	Tukey-Kramer	0.9998	0.05	-0.2976	0.2729	-0.3867	0.3620
tissu			END			LM	-2.4800	0.1451	379	-17.10	<.0001	Tukey-Kramer	<.0001	0.05	-2.7653	-2.1948	-2.8543	-2.1057
tissu			END			UM	-2.1938	0.1451	379	-15.12	<.0001	Tukey-Kramer	<.0001	0.05	-2.4790	-1.9085	-2.5681	-1.8194
tissu			IT			LM	-2.4677	0.1451	379	-17.01	<.0001	Tukey-Kramer	<.0001	0.05	-2.7529	-2.1825	-2.8420	-2.0934
tissu			IT			UM	-2.1814	0.1451	379	-15.04	<.0001	Tukey-Kramer	<.0001	0.05	-2.4666	-1.8962	-2.5557	-1.8071
tissu			LM			UM	0.2863	0.1451	379	1.97	0.0492	Tukey-Kramer	0.1998	0.05	0.001068	0.5715	-0.08803	0.6606

Interpretation

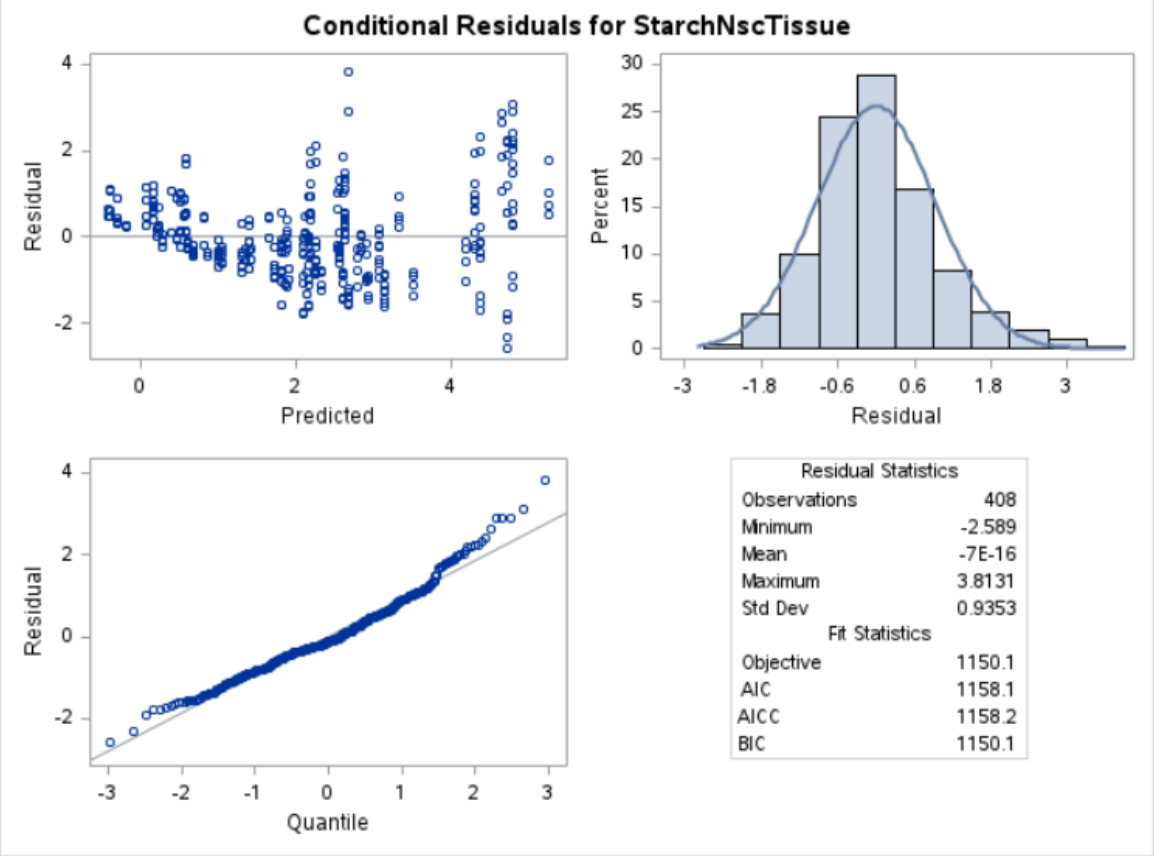


Figure 12: Fig-4

Interpretation

Nested Model

```
/* Hierarchial Nested Model*/

proc mixed data=data method=reml plots=(residualpanel);
    class treatment tissu dayPeriod campagne chamber sample;
    model StarchNscTissue = treatment | tissu | dayPeriod;
    random campagne chamber(campagne) sample(chamber*campagne);
    lsmeans treatment tissu dayPeriod / pdiff=all cl adjust=tukey;
run;
```

Output

Covariance Parameter Estimates	
Cov Parm	Estimate
campagne	0.5207
chamber(campagne)	0.2477
sampl(campag*chambe)	0.000819
Residual	0.9277

Fit Statistics	
-2 Res Log Likelihood	1151.9
AIC (Smaller is Better)	1159.9
AICC (Smaller is Better)	1160.0
BIC (Smaller is Better)	1154.6

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
treatment	1	386	4.38	0.0371
tissu	3	386	172.72	<.0001
treatment*tissu	3	386	13.06	<.0001
dayPeriod	1	386	2.93	0.0877
treatment*dayPeriod	1	386	0.17	0.6823
tissu*dayPeriod	3	386	2.14	0.0950
treatm*tissu*dayPeri	3	386	0.45	0.7153

Interpretation

Least Squares Means

Effect	treatment	tissu	dayPeriod	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
treatment	Control			2.2854	0.5725	386	3.99	<.0001	0.05	1.1598	3.4110
treatment	Drought			1.5169	0.5726	386	2.65	0.0084	0.05	0.3911	2.6427
tissu		END		0.7296	0.5496	386	1.33	0.1851	0.05	-0.3509	1.8101
tissu		IT		0.7420	0.5496	386	1.35	0.1778	0.05	-0.3385	1.8225
tissu		LM		3.2097	0.5496	386	5.84	<.0001	0.05	2.1292	4.2902
tissu		UM		2.9234	0.5496	386	5.32	<.0001	0.05	1.8429	4.0039
dayPeriod			Day	1.8129	0.5430	386	3.34	0.0009	0.05	0.7454	2.8805
dayPeriod			Night	1.9894	0.5465	386	3.64	0.0003	0.05	0.9149	3.0639

Interpretation

Differences of Least Squares Means

Effect	treatment	tissu	dayPeriod	_treatment	_tissu	_dayPeriod	Estimate	Standard Error	DF	t Value	Pr > |t|	Adjustment	Adj P	Alpha	Lower	Upper	Adj Lower	Adj Upper
treatment	Control			Drought			0.7685	0.3673	386	2.09	0.0371	Tukey-Kramer	0.0371	0.05	0.04639	1.4905	0.04639	1.4905
tissu		END			IT		-0.01234	0.1453	386	-0.08	0.9324	Tukey-Kramer	0.9998	0.05	-0.2981	0.2734	-0.3874	0.3627
tissu		END			LM		-2.4800	0.1453	386	-17.06	<.0001	Tukey-Kramer	<.0001	0.05	-2.7658	-2.1943	-2.8551	-2.1050
tissu		END			UM		-2.1938	0.1453	386	-15.09	<.0001	Tukey-Kramer	<.0001	0.05	-2.4795	-1.9080	-2.5688	-1.8187
tissu		IT			LM		-2.4677	0.1453	386	-16.98	<.0001	Tukey-Kramer	<.0001	0.05	-2.7535	-2.1819	-2.8427	-2.0927
tissu		IT			UM		-2.1814	0.1453	386	-15.01	<.0001	Tukey-Kramer	<.0001	0.05	-2.4672	-1.8956	-2.5565	-1.8064
tissu		LM			UM		0.2863	0.1453	386	1.97	0.0496	Tukey-Kramer	0.2013	0.05	0.000505	0.5721	-0.08876	0.6613
dayPeriod			Day			Night	-0.1764	0.1031	386	-1.71	0.0877	Tukey-Kramer	0.0877	0.05	-0.3791	0.02622	-0.3791	0.02622

Interpretation

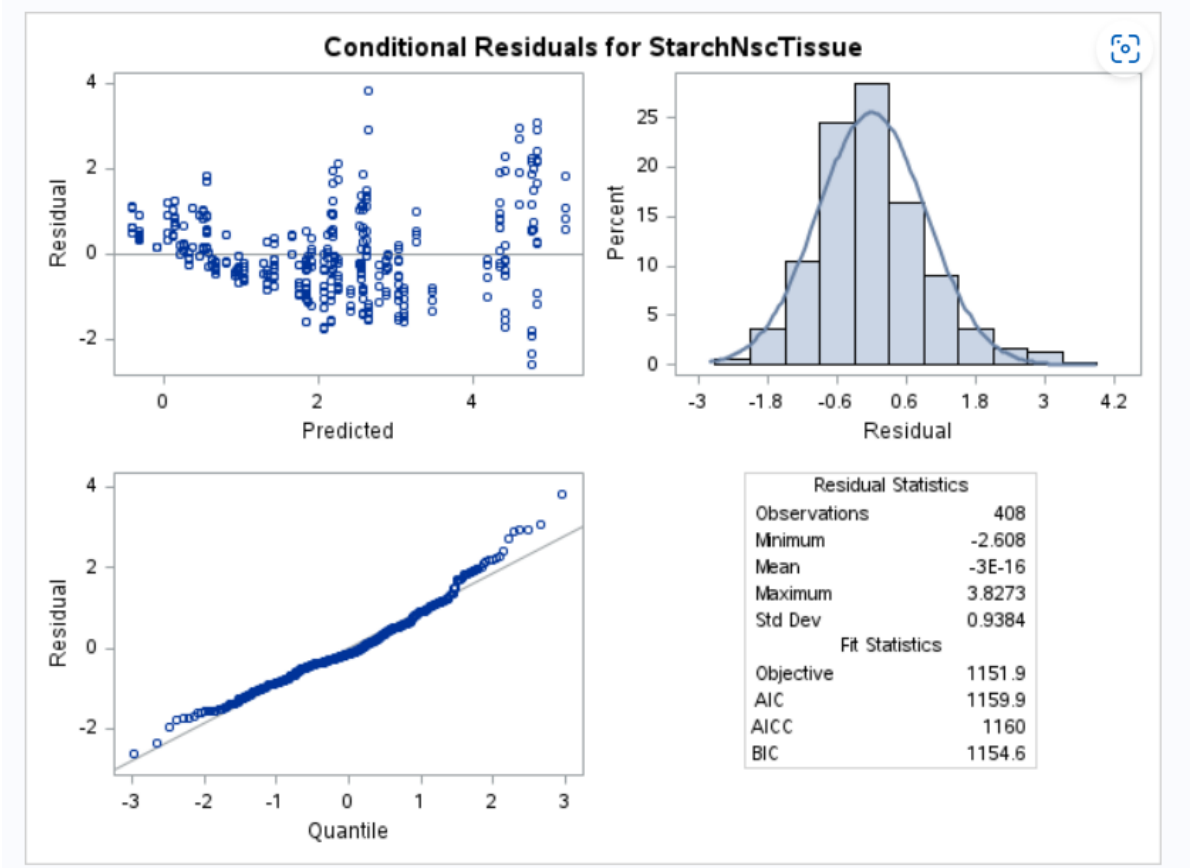


Figure 13: Fig-4

GLMM Model

```
/* GLMM Model */
proc glimmix data=data method=laplace plots=(residualpanel);
    class tissu treatment dayPeriod campagne sample chamber;
    model StarchNscTissue = tissu|treatment|dayPeriod / dist=gamma;
    random campagne sample chamber;
    lsmeans treatment dayPeriod tissu / pdiff=all cl adjust=tukey;
run;
```

Output

Fit Statistics	
-2 Log Likelihood	847.34
AIC (smaller is better)	887.34
AICC (smaller is better)	889.51
BIC (smaller is better)	861.20
CAIC (smaller is better)	881.20
HQIC (smaller is better)	832.68

Fit Statistics for Conditional Distribution	
-2 log L(StarchNscTissue | r. effects)	812.56
Pearson Chi-Square	108.96
Pearson Chi-Square / DF	0.27

Covariance Parameter Estimates		
Cov Parm	Estimate	Standard Error
campagne	0.008966	0.05038
sample	0.1116	0.08512
chamber	0.02969	.
Residual	0.2664	0.01805

Type III Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
tissu	3	386	217.81	<.0001
treatment	1	386	0.68	0.4095
tissu*treatment	3	386	4.60	0.0036
dayPeriod	1	386	0.90	0.3436
tissu*dayPeriod	3	386	1.67	0.1724
treatment*dayPeriod	1	386	1.62	0.2039
tissu*treatm*dayPeri	3	386	1.76	0.1551

Interpretation

treatment Least Squares Means								
treatment	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Control	0.4396	0.2033	386	2.16	0.0312	0.05	0.03987	0.8394
Drought	0.2154	0.2034	386	1.06	0.2902	0.05	-0.1845	0.6153

Differences of treatment Least Squares Means Adjustment for Multiple Comparisons: Tukey-Kramer												
treatment	_treatment	Estimate	Standard Error	DF	t Value	Pr > |t|	Adj P	Alpha	Lower	Upper	Adj Lower	Adj Upper
Control	Drought	0.2242	0.2715	386	0.83	0.4095	0.4095	0.05	-0.3097	0.7581	-0.3097	0.7581

dayPeriod Least Squares Means								
dayPeriod	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
Day	0.3012	0.1521	386	1.98	0.0483	0.05	0.002198	0.6002
Night	0.3539	0.1557	386	2.27	0.0236	0.05	0.04768	0.6600

Differences of dayPeriod Least Squares Means Adjustment for Multiple Comparisons: Tukey-Kramer												
dayPeriod	_dayPeriod	Estimate	Standard Error	DF	t Value	Pr > |t|	Adj P	Alpha	Lower	Upper	Adj Lower	Adj Upper
Day	Night	-0.05266	0.05553	386	-0.95	0.3436	0.3436	0.05	-0.1618	0.05652	-0.1618	0.05652

tissu Least Squares Means								
tissu	Estimate	Standard Error	DF	t Value	Pr > |t|	Alpha	Lower	Upper
END	-0.3593	0.1588	386	-2.26	0.0242	0.05	-0.6715	-0.04710
IT	-0.4292	0.1591	386	-2.70	0.0073	0.05	-0.7420	-0.1164
LM	1.1093	0.1589	386	6.98	<.0001	0.05	0.7969	1.4216
UM	0.9894	0.1589	386	6.23	<.0001	0.05	0.6770	1.3018

Differences of tissu Least Squares Means Adjustment for Multiple Comparisons: Tukey-Kramer												
tissu	_tissu	Estimate	Standard Error	DF	t Value	Pr > |t|	Adj P	Alpha	Lower	Upper	Adj Lower	Adj Upper
END	IT	0.06992	0.07865	386	0.89	0.3746	0.8106	0.05	-0.08472	0.2246	-0.1330	0.2729
END	LM	-1.4686	0.07869	386	-18.66	<.0001	<.0001	0.05	-1.6233	-1.3139	-1.6716	-1.2656
END	UM	-1.3487	0.07885	386	-17.11	<.0001	<.0001	0.05	-1.5037	-1.1937	-1.5521	-1.1453
IT	LM	-1.5385	0.07968	386	-19.31	<.0001	<.0001	0.05	-1.6952	-1.3819	-1.7441	-1.3329
IT	UM	-1.4186	0.07958	386	-17.83	<.0001	<.0001	0.05	-1.5751	-1.2621	-1.6240	-1.2133
LM	UM	0.1199	0.07808	386	1.54	0.1255	0.4172	0.05	-0.03362	0.2734	-0.08156	0.3213

Interpretation

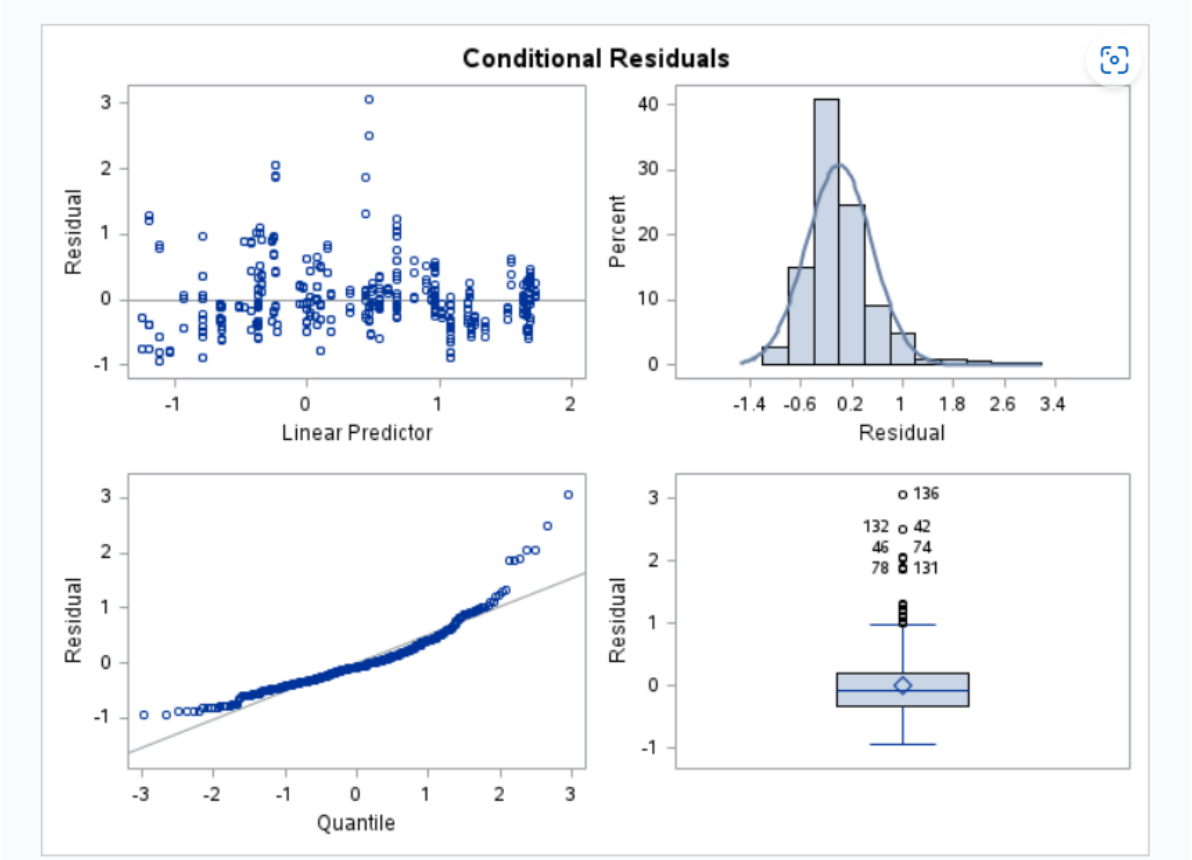


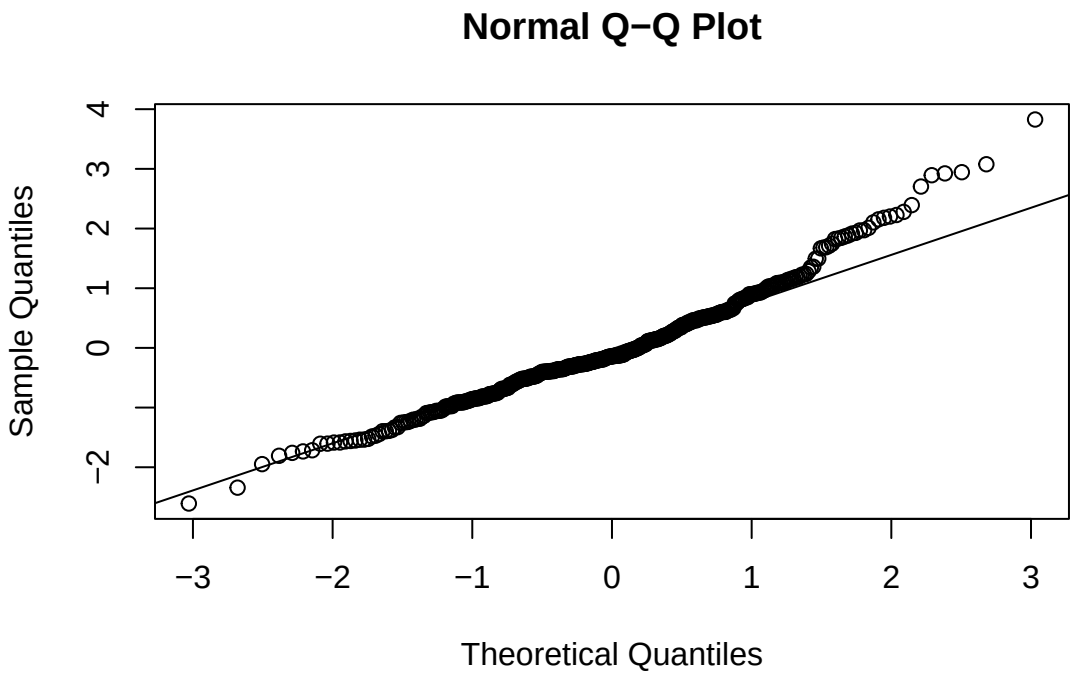
Figure 14: Fig-3

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: StarchNscTissue ~ tissu * treatment * dayPeriod + (1 | campagne) +
    (1 | sample) + (1 | chamber)
   Data: data

REML criterion at convergence: 1151.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.7075 -0.5735 -0.1460  0.5321  3.9737

Random effects:
 Groups   Name        Variance Std.Dev.
 chamber  (Intercept) 0.03069  0.1752
```

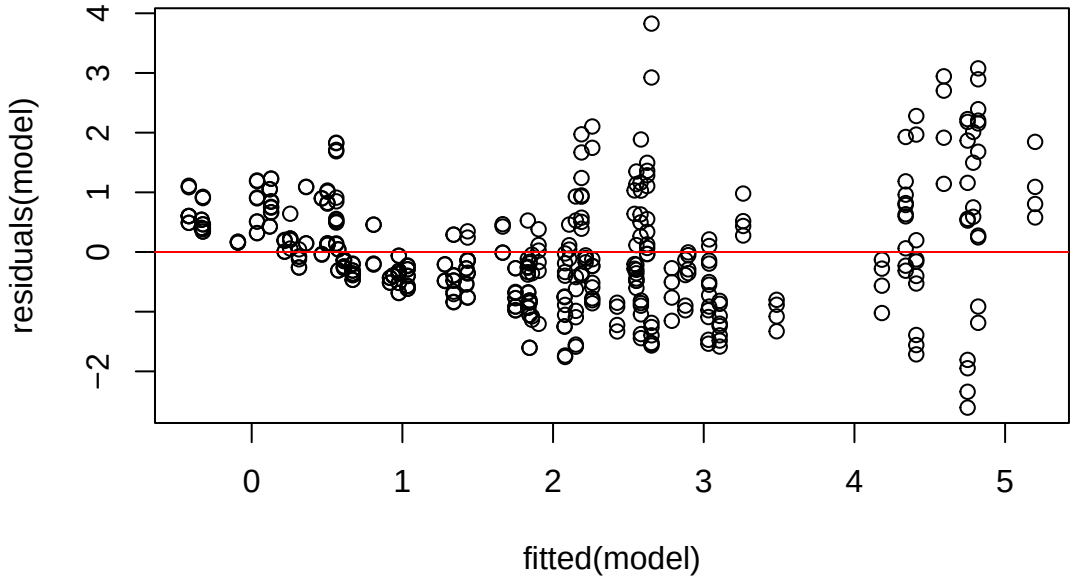
```
 sample   (Intercept) 0.21782  0.4667
 campagne (Intercept) 0.52077  0.7216
 Residual             0.92767  0.9632
Number of obs: 408, groups:  chamber, 8; sample, 8; campagne, 2

Fixed effects:
                                          Estimate Std. Error        df t value
(Intercept)                                0.67729    0.59020   1.40265   1.148
tissuIT                                    0.09316    0.22702 386.01503   0.410
tissuLM                                    3.00031    0.22702 386.01503  13.216
tissuUM                                    3.07044    0.22702 386.01503  13.525
treatmentDrought                          -0.09047    0.42136   8.85231  -0.215
dayPeriodNight                             0.08438    0.28949 386.03418   0.291
tissuIT:treatmentDrought                  -0.03511    0.32574 386.01503  -0.108
tissuLM:treatmentDrought                  -1.42355    0.32574 386.01503  -4.370
tissuUM:treatmentDrought                  -1.42214    0.32574 386.01503  -4.366
tissuIT:dayPeriodNight                     0.14820    0.40926 386.01503   0.362
tissuLM:dayPeriodNight                     0.36356    0.40926 386.01503   0.888
tissuUM:dayPeriodNight                    -0.31235    0.40926 386.01503  -0.763
treatmentDrought:dayPeriodNight            0.22150    0.41139 386.09586   0.538
tissuIT:treatmentDrought:dayPeriodNight   -0.54948    0.58140 386.01503  -0.945
tissuLM:treatmentDrought:dayPeriodNight    0.03887    0.58140 386.01503   0.067
tissuUM:treatmentDrought:dayPeriodNight   -0.03772    0.58140 386.01503  -0.065
                                         Pr(>|t|)
(Intercept)                                 0.410
tissuIT                                     0.682
tissuLM                                   < 2e-16 ***
tissuUM                                   < 2e-16 ***
treatmentDrought                            0.835
dayPeriodNight                              0.771
tissuIT:treatmentDrought                    0.914
tissuLM:treatmentDrought                 1.60e-05 ***
tissuUM:treatmentDrought                 1.63e-05 ***
tissuIT:dayPeriodNight                      0.717
tissuLM:dayPeriodNight                      0.375
tissuUM:dayPeriodNight                      0.446
treatmentDrought:dayPeriodNight             0.591
tissuIT:treatmentDrought:dayPeriodNight     0.345
tissuLM:treatmentDrought:dayPeriodNight     0.947
tissuUM:treatmentDrought:dayPeriodNight     0.948
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
optimizer (nloptwrap) convergence code: 0 (OK)
```

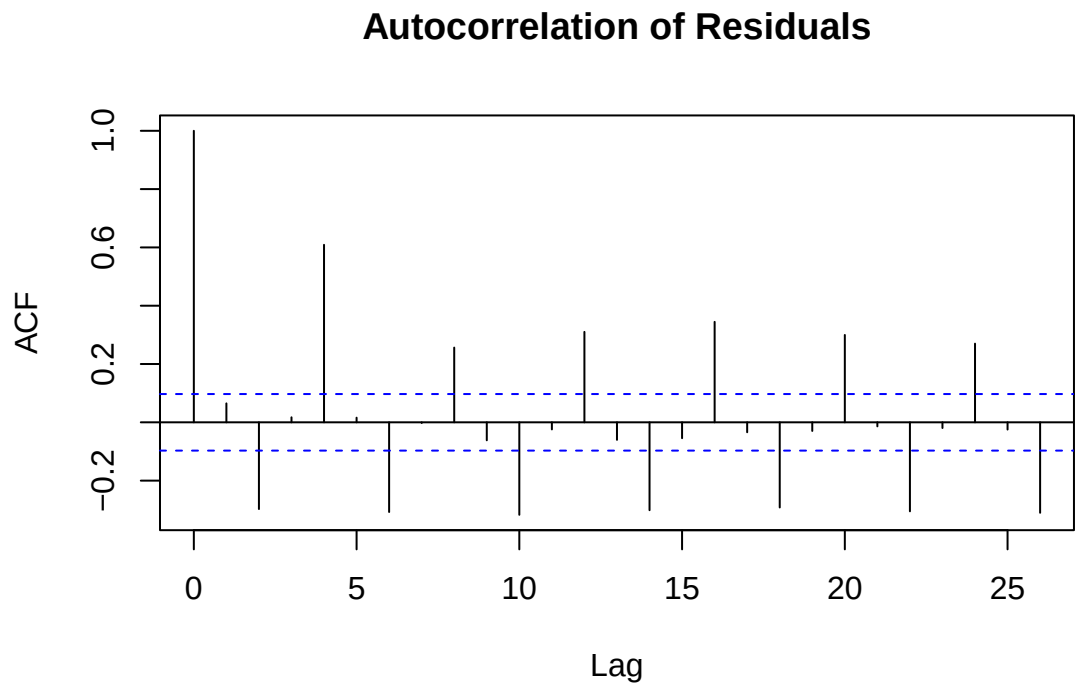
```
unable to evaluate scaled gradient
Model failed to converge: degenerate  Hessian with 1 negative eigenvalues

[1] 1191.869

[1] 1272.094

Type III Analysis of Variance Table with Satterthwaite's method
                          Sum Sq Mean Sq NumDF  DenDF  F value    Pr(>F)
tissu                     480.67 160.224     3 386.02 172.7160 < 2.2e-16 ***
treatment                   4.06   4.062     1   5.12   4.3784   0.08934 .
dayPeriod                   2.72   2.718     1 386.13   2.9302   0.08774 .
tissu:treatment            36.35  12.116     3 386.02  13.0608 3.848e-08 ***
tissu:dayPeriod             5.95   1.983     3 386.02   2.1380   0.09496 .
treatment:dayPeriod         0.16   0.156     1 386.33   0.1677   0.68235
tissu:treatment:dayPeriod   1.26   0.420     3 386.02   0.4530   0.71531
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Checking assumption



```
    Shapiro-Wilk normality test

data:  residuals(model)
W = 0.97114, p-value = 3.211e-07
```





Model 3: Nested Model for DayPeriod and Time Effects In this model, dayPeriod is used as a broader time effect, with time nested within dayPeriod.

```
/* Mixed Model*/
proc mixed data=data method=reml plots=(residualpanel);
    class treatment tissu dayPeriod campagne chamber;
    model StarchNscTissue = treatment|tissu|dayPeriod;
    lsmeans treatment dayPeriod tissu / pdiff=all cl adjust=tukey;
    random campagne chamber sample;
run;
```

This model also includes campagne, sample, and chamber as random effects.

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: StarchNscTissue ~ tissu + treatment + dayPeriod + dayPeriod:time +
    (1 | campagne) + (1 | sample) + (1 | chamber)
   Data: data
```

```
REML criterion at convergence: 1192.6

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.2829 -0.6858 -0.0363  0.4039  3.8747

Random effects:
 Groups   Name        Variance Std.Dev.
 chamber  (Intercept) 0.0276   0.1661
 sample   (Intercept) 0.2245   0.4738
 campagne (Intercept) 0.5451   0.7383
 Residual             1.0075   1.0037
Number of obs: 408, groups:  chamber, 8; sample, 8; campagne, 2

Fixed effects:
                     Estimate Std. Error        df t value Pr(>|t|)
(Intercept)           0.80373    0.59686   1.34648   1.347 0.360931
tissuIT               0.03626    0.14055 392.01679   0.258 0.796569
tissuLM               2.42265    0.14055 392.01679  17.237  < 2e-16 ***
tissuUM               2.26940    0.14055 392.01679  16.147  < 2e-16 ***
treatmentDrought     -0.77436    0.36888   5.01240  -2.099 0.089702 .
dayPeriodNight        0.36950    0.16284 392.08694   2.269 0.023804 *
dayPeriodDay:timeB    0.24285    0.16591 392.19489   1.464 0.144068
dayPeriodNight:timeC  0.04250    0.17744 392.01679   0.240 0.810825
dayPeriodDay:timeE    0.12013    0.16284 392.08694   0.738 0.461138
dayPeriodDay:timeF    0.62719    0.16591 392.19489   3.780 0.000181 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) tissIT tissLM tissUM trtmnD dyPrdN dyPD:B dyPN:C dyPD:E
tissuIT     -0.118
tissuLM     -0.118  0.500
tissuUM     -0.118  0.500  0.500
trtmntDrght -0.309  0.000  0.000  0.000
dayPerdNght -0.111  0.000  0.000  0.000 -0.001
dyPrdDy:tmB -0.110  0.000  0.000  0.000  0.006  0.396
dyPrdNght:C  0.000  0.000  0.000  0.000  0.000 -0.545  0.000
dyPrdDy:tmE -0.111  0.000  0.000  0.000 -0.001  0.406  0.396  0.000
dyPrdDy:tmF -0.110  0.000  0.000  0.000  0.006  0.396  0.390  0.000  0.396
fit warnings:
fixed-effect model matrix is rank deficient so dropping 6 columns / coefficients
```

```
[1] 1220.641
```

```
[1] 1276.799
```

```
Type III Analysis of Variance Table with Satterthwaite's method
               Sum Sq Mean Sq NumDF  DenDF  F value    Pr(>F)
tissu          554.01 184.671     3 392.02 183.3018 < 2.2e-16 ***
treatment        4.44   4.440     1   5.01   4.4068  0.089702 .
dayPeriod        5.19   5.187     1 392.09   5.1489  0.023804 *
dayPeriod:time  15.20   3.801     4 392.11   3.7724  0.005036 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
    Shapiro-Wilk normality test

data:  residuals(model3)
W = 0.96174, p-value = 8.022e-09
```

```
Call:
lm(formula = StarchNscTissue ~ treatment * tissu * dayPeriod +
    campagne, data = data)

Residuals:
    Min      1Q  Median      3Q     Max
-2.1490 -0.6395 -0.1383  0.5298  3.5674

Coefficients:
                                    Estimate Std. Error t value Pr(>|t|)
(Intercept)                         -0.93022    0.23779  -3.912 0.000108
treatmentDrought                    -0.17885    0.24974  -0.716 0.474327
tissuIT                              0.09316    0.24612   0.379 0.705243
tissuLM                              3.00031    0.24612  12.190  < 2e-16
tissuUM                              3.07044    0.24612  12.475  < 2e-16
dayPeriodNight                       0.04878    0.31380   0.155 0.876544
campagne                             1.09540    0.10416  10.516  < 2e-16
treatmentDrought:tissuIT            -0.03511    0.35315  -0.099 0.920866
treatmentDrought:tissuLM            -1.42355    0.35315  -4.031 6.68e-05
treatmentDrought:tissuUM            -1.42214    0.35315  -4.027 6.79e-05
```

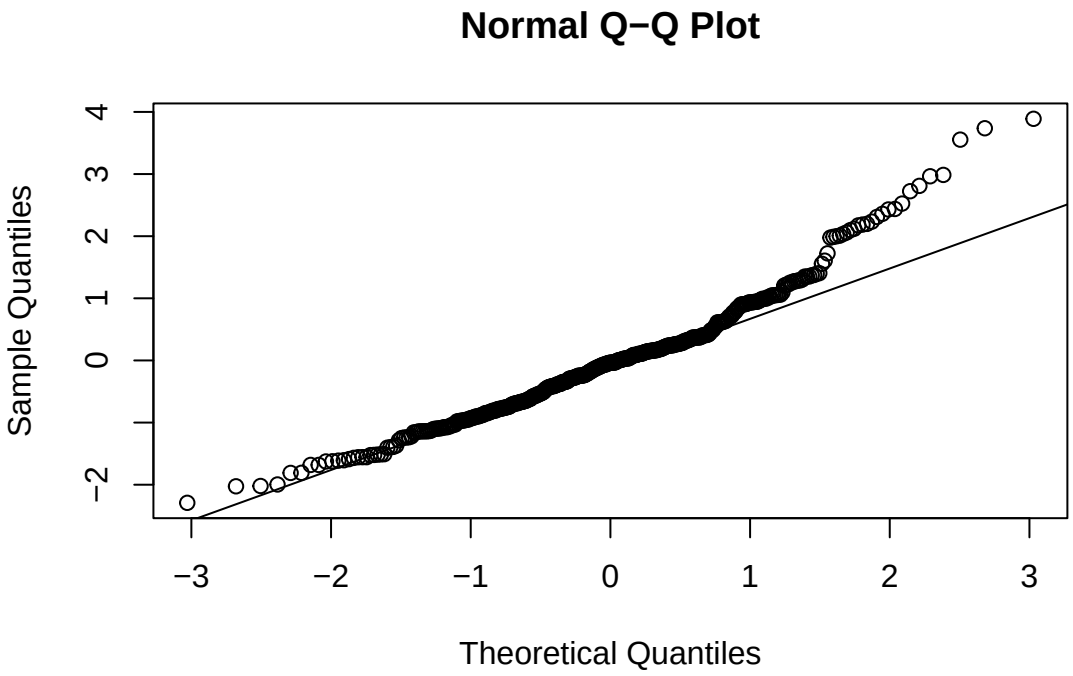

Normal Q−Q Plot
Sample Quantiles
Theoretical Quantiles
−2
0
1
2
3
4
−3
−2
−1
0
1
2
3

Figure 15

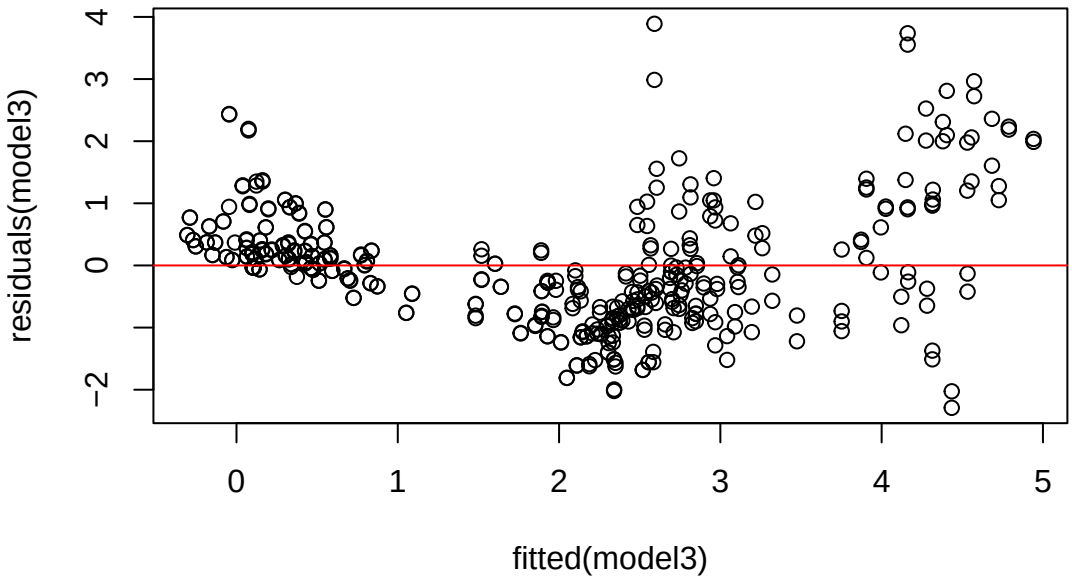


Figure 16

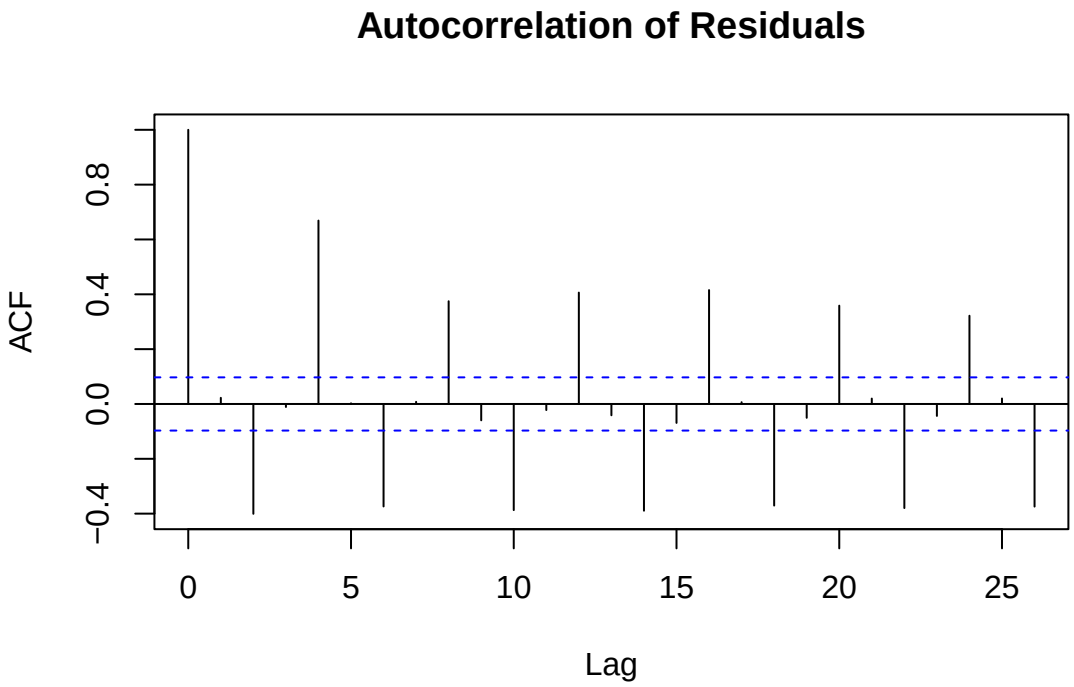
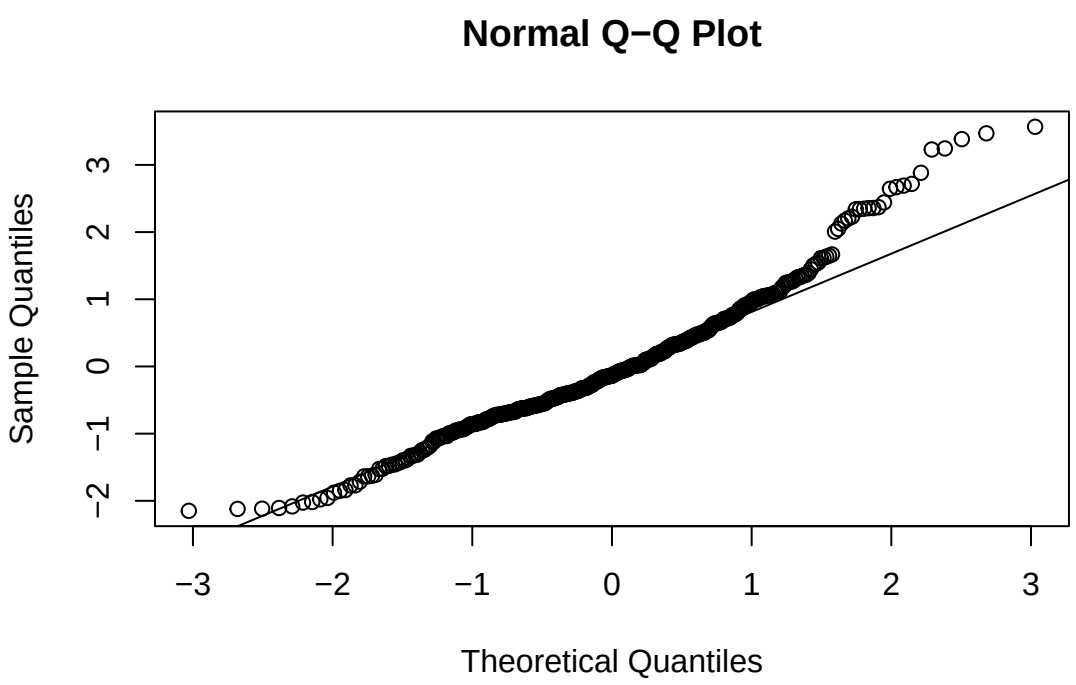
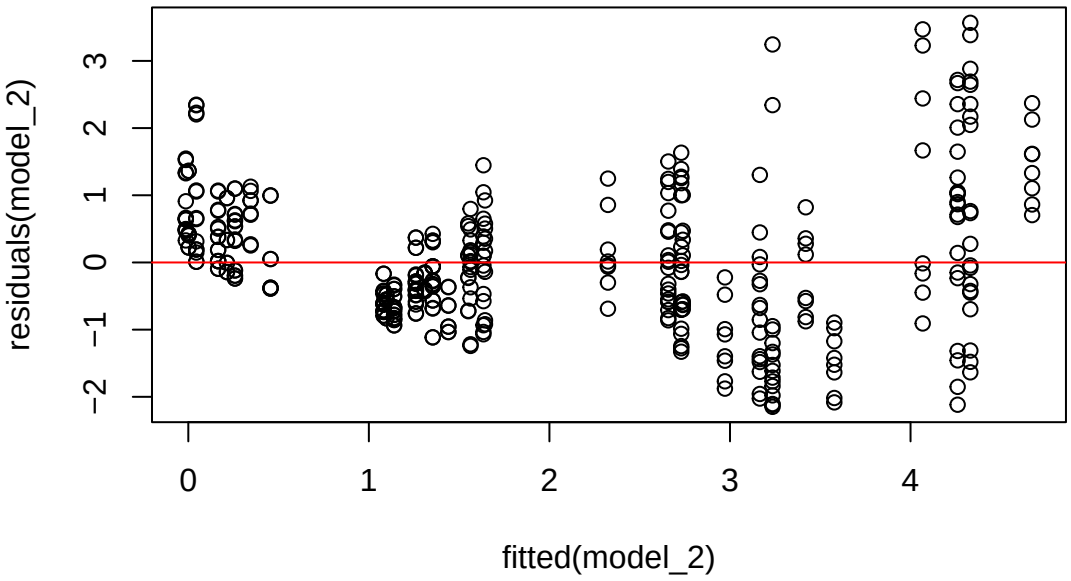

Autocorrelation of Residuals
ACF
0.8
0.4
0.0
−0.4
0
5
10
15
20
25
Lag

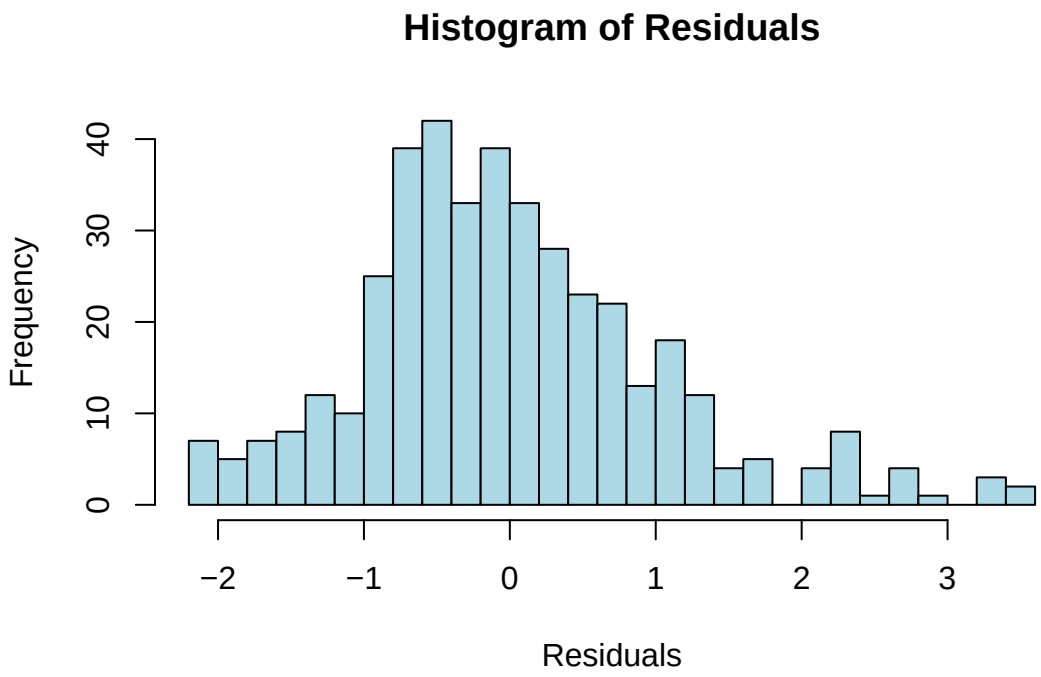
Figure 17

```
treatmentDrought:dayPeriodNight          0.30988    0.44572   0.695 0.487317
tissuIT:dayPeriodNight                   0.14820    0.44370   0.334 0.738553
tissuLM:dayPeriodNight                   0.36356    0.44370   0.819 0.413066
tissuUM:dayPeriodNight                  -0.31235    0.44370  -0.704 0.481870
treatmentDrought:tissuIT:dayPeriodNight -0.54948    0.63032  -0.872 0.383883
treatmentDrought:tissuLM:dayPeriodNight  0.03887    0.63032   0.062 0.950859
treatmentDrought:tissuUM:dayPeriodNight -0.03772    0.63032  -0.060 0.952308

(Intercept)                             ***
treatmentDrought
tissuIT
tissuLM                                 ***
tissuUM                                 ***
dayPeriodNight
campagne                                ***
treatmentDrought:tissuIT
treatmentDrought:tissuLM                ***
treatmentDrought:tissuUM                ***
treatmentDrought:dayPeriodNight
tissuIT:dayPeriodNight
tissuLM:dayPeriodNight
tissuUM:dayPeriodNight
treatmentDrought:tissuIT:dayPeriodNight
treatmentDrought:tissuLM:dayPeriodNight
treatmentDrought:tissuUM:dayPeriodNight
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.044 on 391 degrees of freedom
Multiple R-squared:  0.6513,    Adjusted R-squared:  0.6371
F-statistic: 45.65 on 16 and 391 DF,  p-value: < 2.2e-16
```



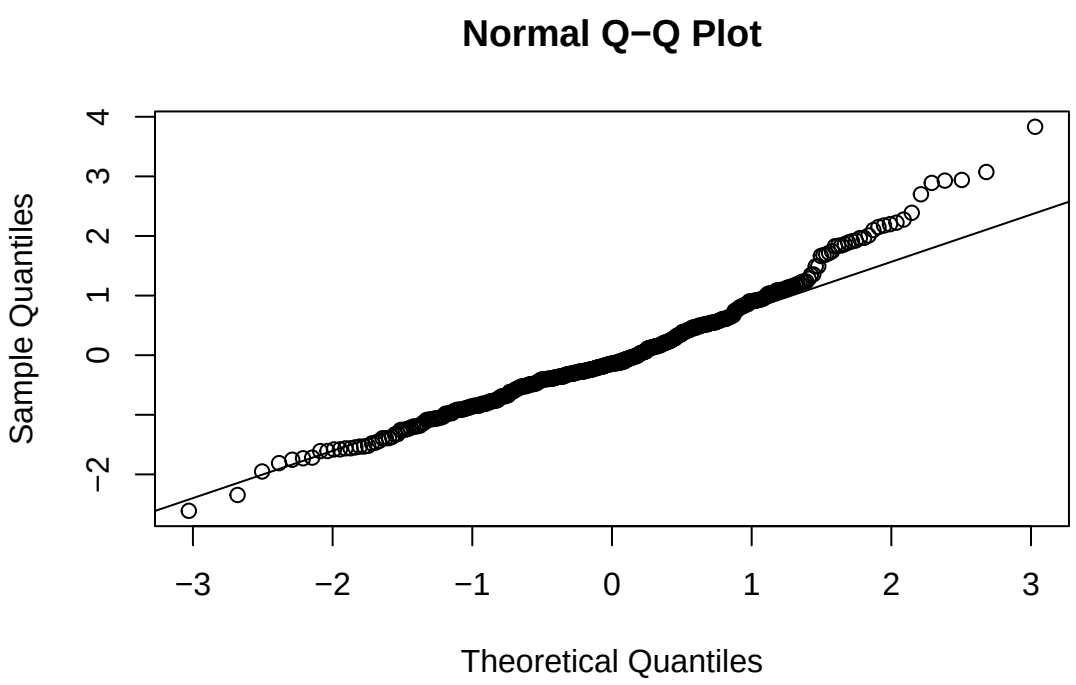

```
    Shapiro-Wilk normality test

data:  residuals(model_2)
W = 0.96501, p-value = 2.709e-08
```


residuals(model_2)
−2
−1
0
1
2
3
0
1
2
3
4
fitted(model_2)

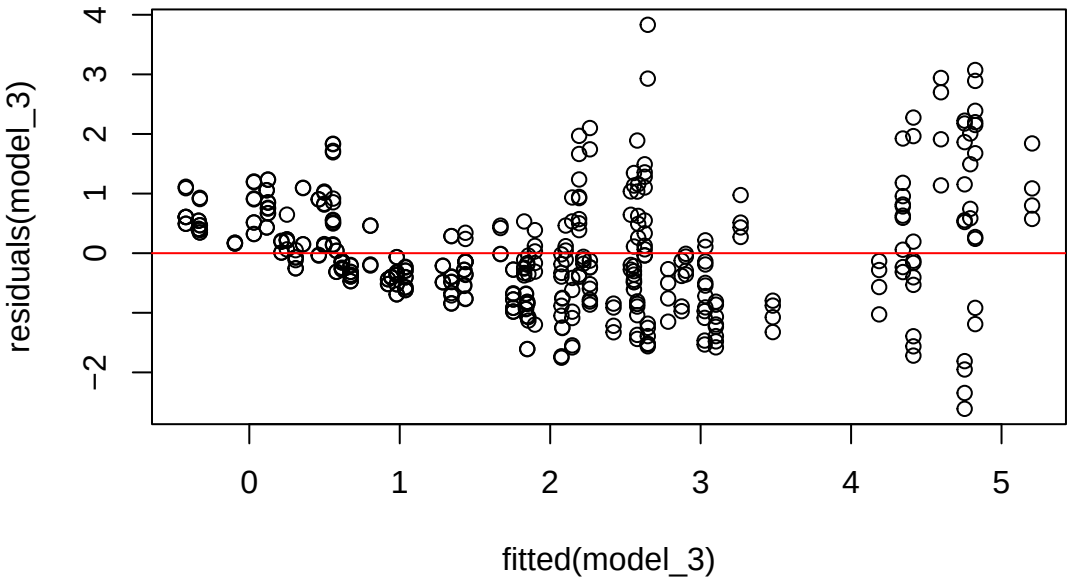


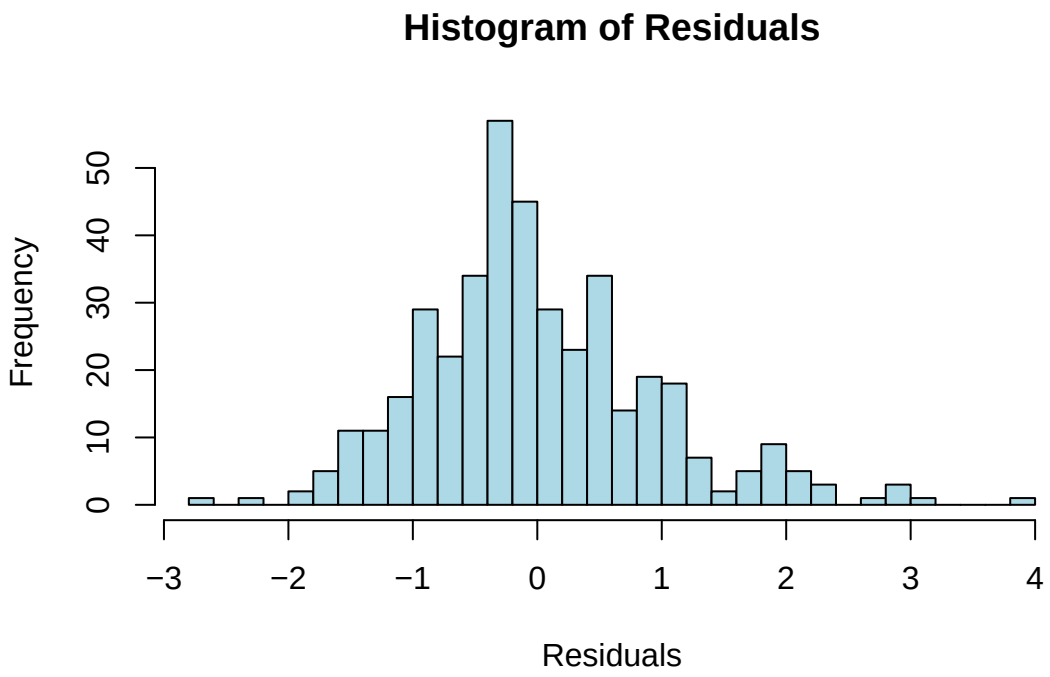

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: StarchNscTissue ~ treatment * tissu * dayPeriod + campagne +
    (1 | chamber)
   Data: data

REML criterion at convergence: 1148.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.7113 -0.5756 -0.1467  0.5350  3.9784

Random effects:
 Groups   Name        Variance Std.Dev.
 chamber  (Intercept) 0.2484   0.4984
 Residual             0.9277   0.9632
Number of obs: 408, groups:  chamber, 8

Fixed effects:
                                        Estimate Std. Error        df t value
```

```
(Intercept)                                -0.94922    0.62429   5.65354  -1.520
treatmentDrought                           -0.09081    0.42131   8.85361  -0.216
tissuIT                                     0.09316    0.22702 386.01184   0.410
tissuLM                                     3.00031    0.22702 386.01184  13.216
tissuUM                                     3.07044    0.22702 386.01184  13.525
dayPeriodNight                              0.08484    0.28949 386.02903   0.293
campagne                                    1.08403    0.36534   5.01449   2.967
treatmentDrought:tissuIT                   -0.03511    0.32574 386.01184  -0.108
treatmentDrought:tissuLM                   -1.42355    0.32574 386.01184  -4.370
treatmentDrought:tissuUM                   -1.42214    0.32574 386.01184  -4.366
treatmentDrought:dayPeriodNight             0.22184    0.41140 386.09222   0.539
tissuIT:dayPeriodNight                      0.14820    0.40926 386.01184   0.362
tissuLM:dayPeriodNight                      0.36356    0.40926 386.01184   0.888
tissuUM:dayPeriodNight                     -0.31235    0.40926 386.01184  -0.763
treatmentDrought:tissuIT:dayPeriodNight    -0.54948    0.58140 386.01184  -0.945
treatmentDrought:tissuLM:dayPeriodNight     0.03887    0.58140 386.01184   0.067
treatmentDrought:tissuUM:dayPeriodNight    -0.03772    0.58140 386.01184  -0.065
                                          Pr(>|t|)
(Intercept)                                 0.1822
treatmentDrought                            0.8342
tissuIT                                     0.6818
tissuLM                                   < 2e-16 ***
tissuUM                                   < 2e-16 ***
dayPeriodNight                              0.7696
campagne                                    0.0311 *
treatmentDrought:tissuIT                    0.9142
treatmentDrought:tissuLM                  1.60e-05 ***
treatmentDrought:tissuUM                  1.63e-05 ***
treatmentDrought:dayPeriodNight             0.5900
tissuIT:dayPeriodNight                      0.7175
tissuLM:dayPeriodNight                      0.3749
tissuUM:dayPeriodNight                      0.4458
treatmentDrought:tissuIT:dayPeriodNight     0.3452
treatmentDrought:tissuLM:dayPeriodNight     0.9467
treatmentDrought:tissuUM:dayPeriodNight     0.9483
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```




```
    Shapiro-Wilk normality test

data:  residuals(model_3)
W = 0.97131, p-value = 3.444e-07
```


residuals(model_3)
−2
0
1
2
3
4
0
1
2
3
4
5
fitted(model_3)

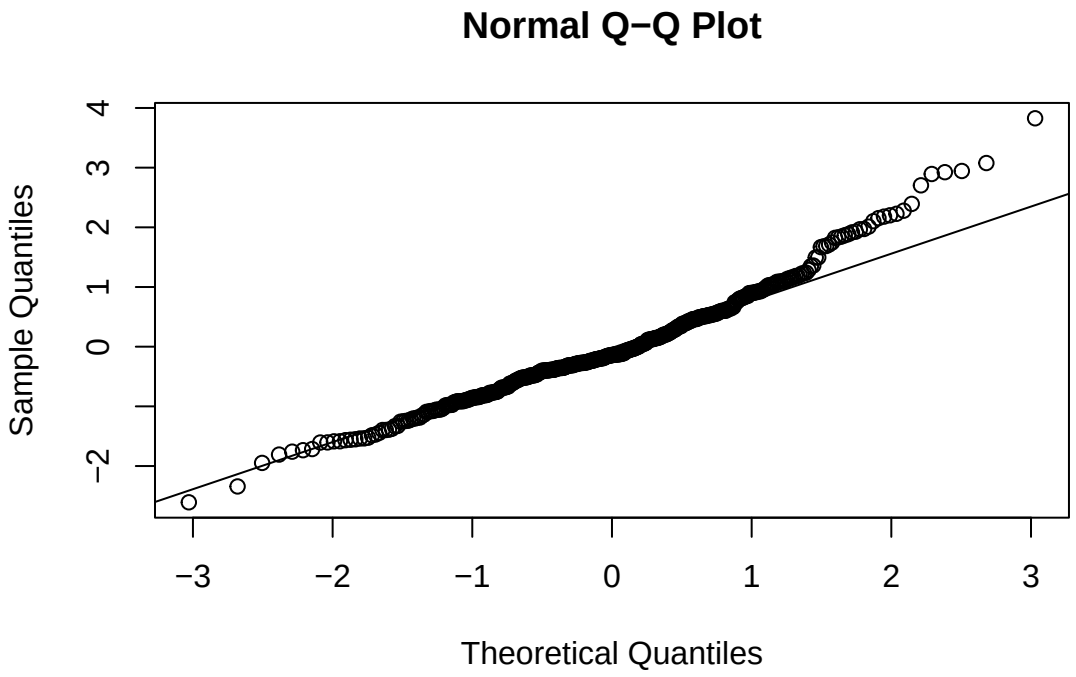


Hierarchial Nested Structured

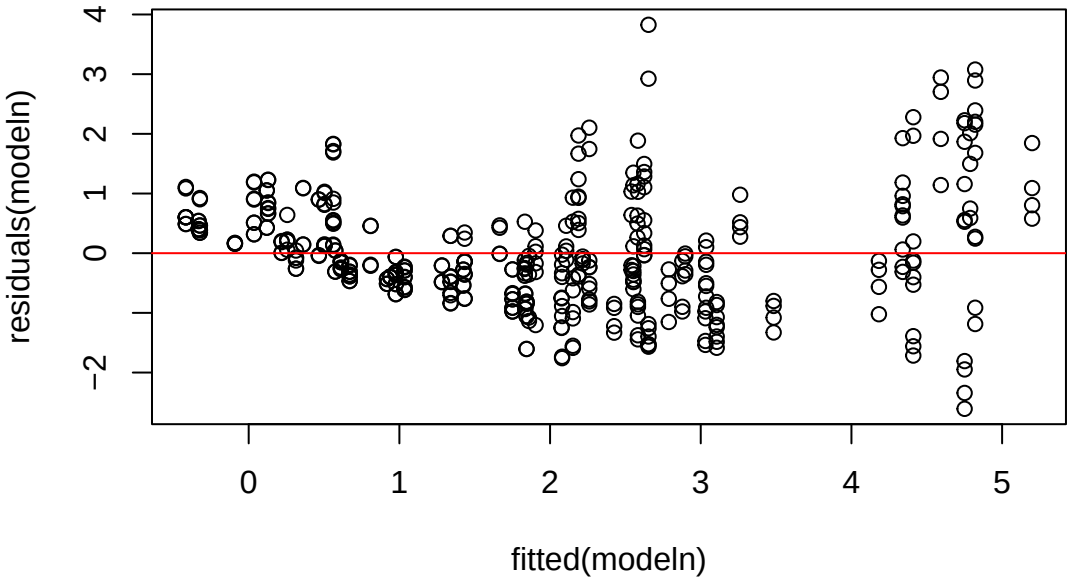
```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: StarchNscTissue ~ treatment * tissu * dayPeriod + (1 | campagne) +
    (1 | campagne:chamber) + (1 | campagne:chamber:sample)
   Data: data

REML criterion at convergence: 1151.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.7075 -0.5735 -0.1460  0.5321  3.9737

Random effects:
 Groups                  Name        Variance Std.Dev.
 campagne:chamber:sample (Intercept) 0.03069  0.1752
 campagne:chamber        (Intercept) 0.21782  0.4667
 campagne                (Intercept) 0.52077  0.7216
```

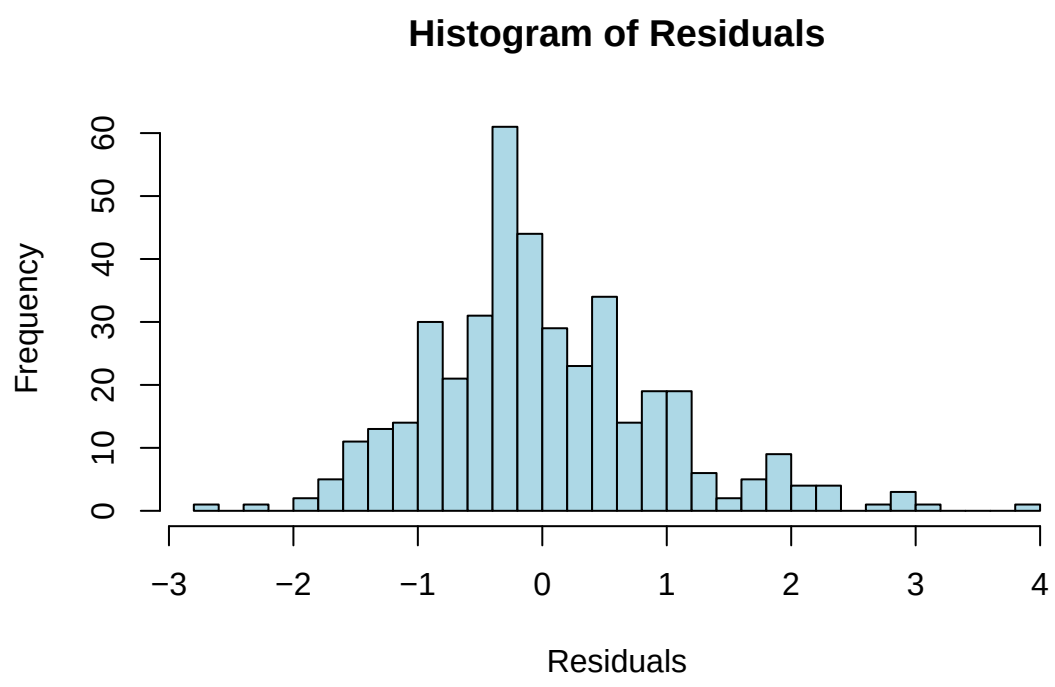
```
 Residual                             0.92767  0.9632
Number of obs: 408, groups:
campagne:chamber:sample, 8; campagne:chamber, 8; campagne, 2

Fixed effects:
                                          Estimate Std. Error        df t value
(Intercept)                                0.67729    0.59020   1.40265   1.148
treatmentDrought                          -0.09047    0.42136   8.85231  -0.215
tissuIT                                    0.09316    0.22702 386.01503   0.410
tissuLM                                    3.00031    0.22702 386.01503  13.216
tissuUM                                    3.07044    0.22702 386.01503  13.525
dayPeriodNight                             0.08438    0.28949 386.03418   0.291
treatmentDrought:tissuIT                  -0.03511    0.32574 386.01503  -0.108
treatmentDrought:tissuLM                  -1.42355    0.32574 386.01503  -4.370
treatmentDrought:tissuUM                  -1.42214    0.32574 386.01503  -4.366
treatmentDrought:dayPeriodNight            0.22150    0.41139 386.09586   0.538
tissuIT:dayPeriodNight                     0.14820    0.40926 386.01503   0.362
tissuLM:dayPeriodNight                     0.36356    0.40926 386.01503   0.888
tissuUM:dayPeriodNight                    -0.31235    0.40926 386.01503  -0.763
treatmentDrought:tissuIT:dayPeriodNight   -0.54948    0.58140 386.01503  -0.945
treatmentDrought:tissuLM:dayPeriodNight    0.03887    0.58140 386.01503   0.067
treatmentDrought:tissuUM:dayPeriodNight   -0.03772    0.58140 386.01503  -0.065
                                         Pr(>|t|)
(Intercept)                                 0.410
treatmentDrought                            0.835
tissuIT                                     0.682
tissuLM                                  < 2e-16 ***
tissuUM                                  < 2e-16 ***
dayPeriodNight                              0.771
treatmentDrought:tissuIT                    0.914
treatmentDrought:tissuLM                 1.60e-05 ***
treatmentDrought:tissuUM                 1.63e-05 ***
treatmentDrought:dayPeriodNight             0.591
tissuIT:dayPeriodNight                      0.717
tissuLM:dayPeriodNight                      0.375
tissuUM:dayPeriodNight                      0.446
treatmentDrought:tissuIT:dayPeriodNight     0.345
treatmentDrought:tissuLM:dayPeriodNight     0.947
treatmentDrought:tissuUM:dayPeriodNight     0.948
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
optimizer (nloptwrap) convergence code: 0 (OK)
unable to evaluate scaled gradient
```

```
Model failed to converge: degenerate  Hessian with 1 negative eigenvalues
```




```
    Shapiro-Wilk normality test

data:  residuals(modeln)
W = 0.97114, p-value = 3.211e-07
```

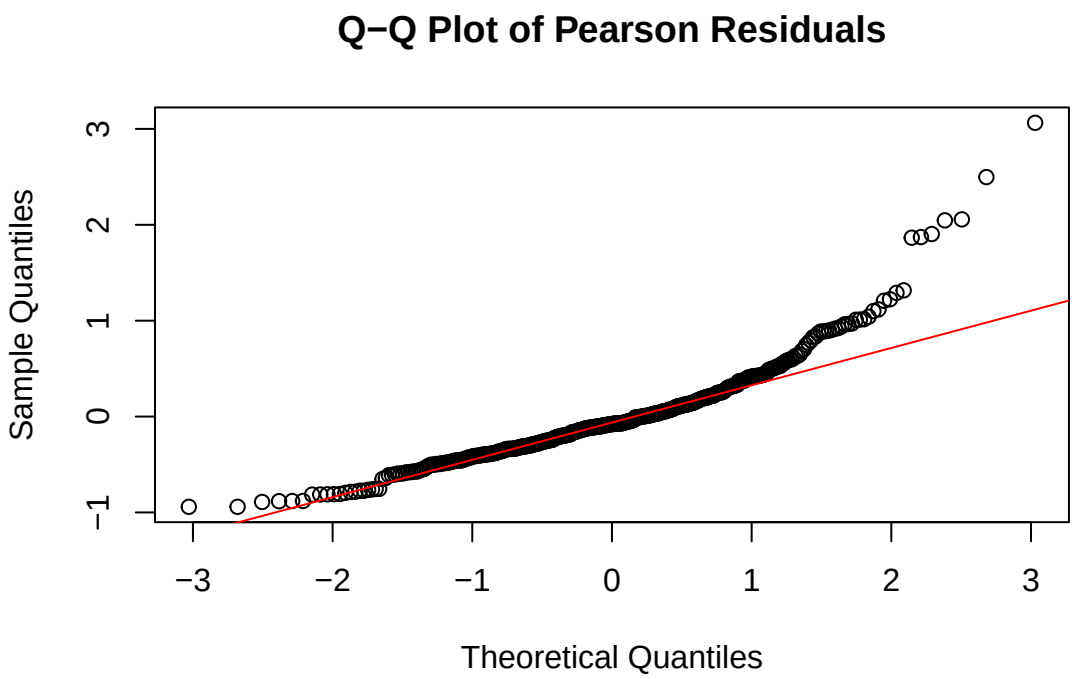

residuals(modeln)
4
3
2
1
0
−2
0
1
2
3
4
5
fitted(modeln)

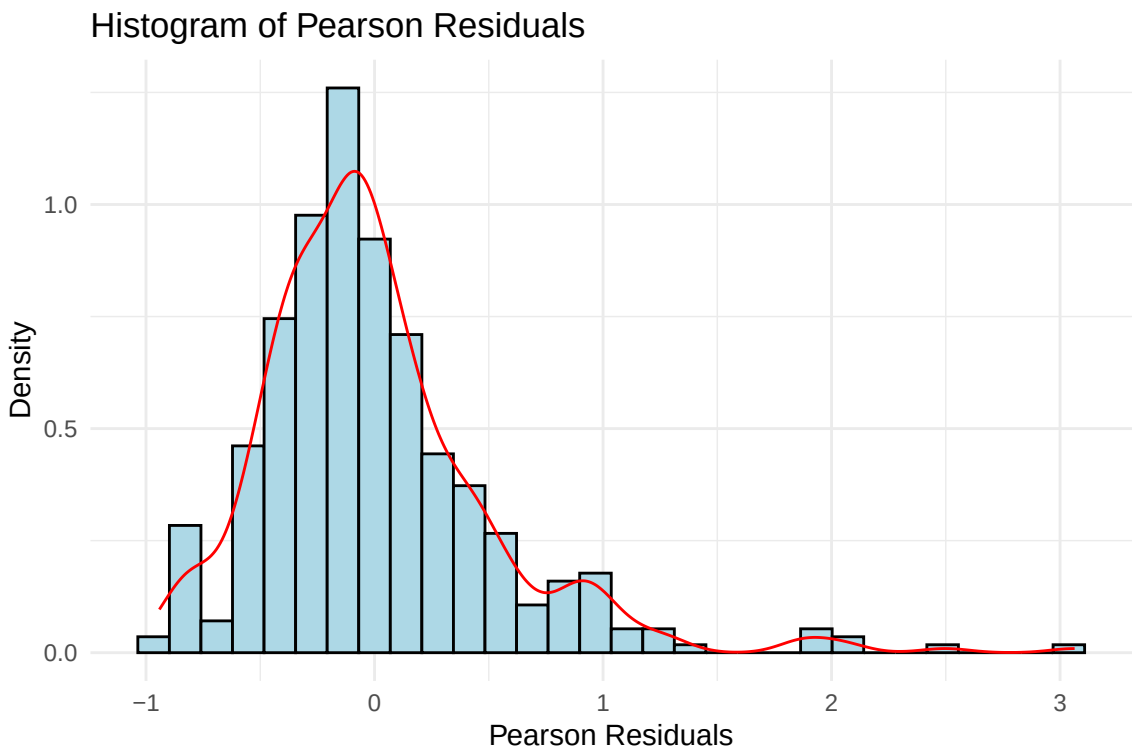


GLMM

```
 Family: Gamma  ( log )
Formula:
StarchNscTissue ~ tissu * treatment * dayPeriod + (1 | campagne) +
    (1 | sample) + (1 | chamber)
Data: data

     AIC      BIC   logLik deviance df.resid
      NA       NA       NA       NA      388

Random effects:

Conditional model:
 Groups   Name        Variance Std.Dev.
 campagne (Intercept) 0.009083 0.0953
 sample   (Intercept) 0.070537 0.2656
 chamber  (Intercept) 0.070537 0.2656
Number of obs: 408, groups:  campagne, 2; sample, 8; chamber, 8
```

```
Dispersion estimate for Gamma family (sigma^2): 0.266

Conditional model:
                                          Estimate Std. Error z value Pr(>|z|)
(Intercept)                               -0.39566    0.21732  -1.821   0.0687
tissuIT                                    0.07835    0.12195   0.643   0.5205
tissuLM                                    1.63964    0.12209  13.430   <2e-16
tissuUM                                    1.66194    0.12261  13.555   <2e-16
treatmentDrought                          -0.11584    0.29298  -0.395   0.6926
dayPeriodNight                            -0.05289    0.15538  -0.340   0.7336
tissuIT:treatmentDrought                  -0.07430    0.17566  -0.423   0.6723
tissuLM:treatmentDrought                  -0.31071    0.17622  -1.763   0.0779
tissuUM:treatmentDrought                  -0.33419    0.17613  -1.897   0.0578
tissuIT:dayPeriodNight                     0.12954    0.21948   0.590   0.5550
tissuLM:dayPeriodNight                     0.10413    0.21950   0.474   0.6352
tissuUM:dayPeriodNight                    -0.09403    0.21939  -0.429   0.6682
treatmentDrought:dayPeriodNight            0.48461    0.22178   2.185   0.0289
tissuIT:treatmentDrought:dayPeriodNight   -0.70449    0.31206  -2.258   0.0240
tissuLM:treatmentDrought:dayPeriodNight   -0.27135    0.31210  -0.869   0.3846
tissuUM:treatmentDrought:dayPeriodNight   -0.39787    0.31261  -1.273   0.2031

(Intercept)                               .
tissuIT
tissuLM                                   ***
tissuUM                                   ***
treatmentDrought
dayPeriodNight
tissuIT:treatmentDrought
tissuLM:treatmentDrought                  .
tissuUM:treatmentDrought                  .
tissuIT:dayPeriodNight
tissuLM:dayPeriodNight
tissuUM:dayPeriodNight
treatmentDrought:dayPeriodNight           *
tissuIT:treatmentDrought:dayPeriodNight   *
tissuLM:treatmentDrought:dayPeriodNight
tissuUM:treatmentDrought:dayPeriodNight
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```


Q−Q Plot of Pearson Residuals
Sample Quantiles
Theoretical Quantiles
−3
−2
−1
0
1
2
3



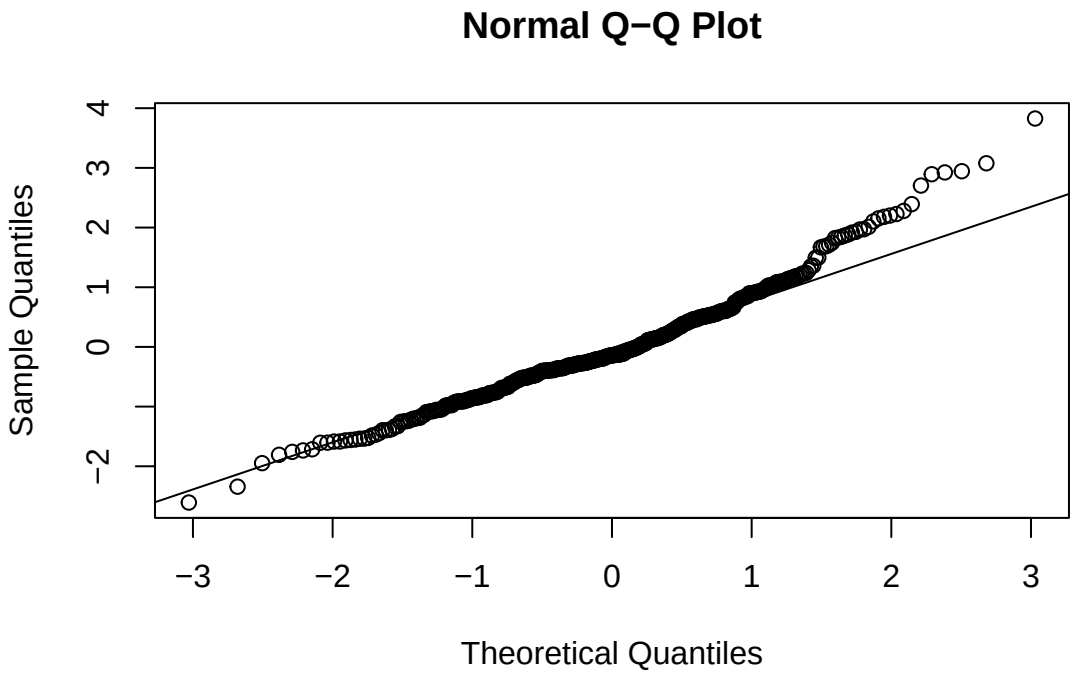

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: StarchNscTissue ~ tissu * treatment * dayPeriod + (1 | campagne) +
    (1 | sample) + (1 | chamber)
   Data: data

REML criterion at convergence: 1151.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.7075 -0.5735 -0.1460  0.5321  3.9737

Random effects:
 Groups   Name        Variance Std.Dev.
 chamber  (Intercept) 0.03069  0.1752
 sample   (Intercept) 0.21782  0.4667
 campagne (Intercept) 0.52077  0.7216
 Residual             0.92767  0.9632
Number of obs: 408, groups:  chamber, 8; sample, 8; campagne, 2
```

```
Fixed effects:
                                          Estimate Std. Error        df t value
(Intercept)                                0.67729    0.59020   1.40265   1.148
tissuIT                                    0.09316    0.22702 386.01503   0.410
tissuLM                                    3.00031    0.22702 386.01503  13.216
tissuUM                                    3.07044    0.22702 386.01503  13.525
treatmentDrought                          -0.09047    0.42136   8.85231  -0.215
dayPeriodNight                             0.08438    0.28949 386.03418   0.291
tissuIT:treatmentDrought                  -0.03511    0.32574 386.01503  -0.108
tissuLM:treatmentDrought                  -1.42355    0.32574 386.01503  -4.370
tissuUM:treatmentDrought                  -1.42214    0.32574 386.01503  -4.366
tissuIT:dayPeriodNight                     0.14820    0.40926 386.01503   0.362
tissuLM:dayPeriodNight                     0.36356    0.40926 386.01503   0.888
tissuUM:dayPeriodNight                    -0.31235    0.40926 386.01503  -0.763
treatmentDrought:dayPeriodNight            0.22150    0.41139 386.09586   0.538
tissuIT:treatmentDrought:dayPeriodNight   -0.54948    0.58140 386.01503  -0.945
tissuLM:treatmentDrought:dayPeriodNight    0.03887    0.58140 386.01503   0.067
tissuUM:treatmentDrought:dayPeriodNight   -0.03772    0.58140 386.01503  -0.065
                                         Pr(>|t|)
(Intercept)                                 0.410
tissuIT                                     0.682
tissuLM                                  < 2e-16 ***
tissuUM                                  < 2e-16 ***
treatmentDrought                            0.835
dayPeriodNight                              0.771
tissuIT:treatmentDrought                    0.914
tissuLM:treatmentDrought                 1.60e-05 ***
tissuUM:treatmentDrought                 1.63e-05 ***
tissuIT:dayPeriodNight                      0.717
tissuLM:dayPeriodNight                      0.375
tissuUM:dayPeriodNight                      0.446
treatmentDrought:dayPeriodNight             0.591
tissuIT:treatmentDrought:dayPeriodNight     0.345
tissuLM:treatmentDrought:dayPeriodNight     0.947
tissuUM:treatmentDrought:dayPeriodNight     0.948
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
optimizer (nloptwrap) convergence code: 0 (OK)
unable to evaluate scaled gradient
Model failed to converge: degenerate  Hessian with 1 negative eigenvalues

[1] 1191.869
```

```
[1] 1272.094
```

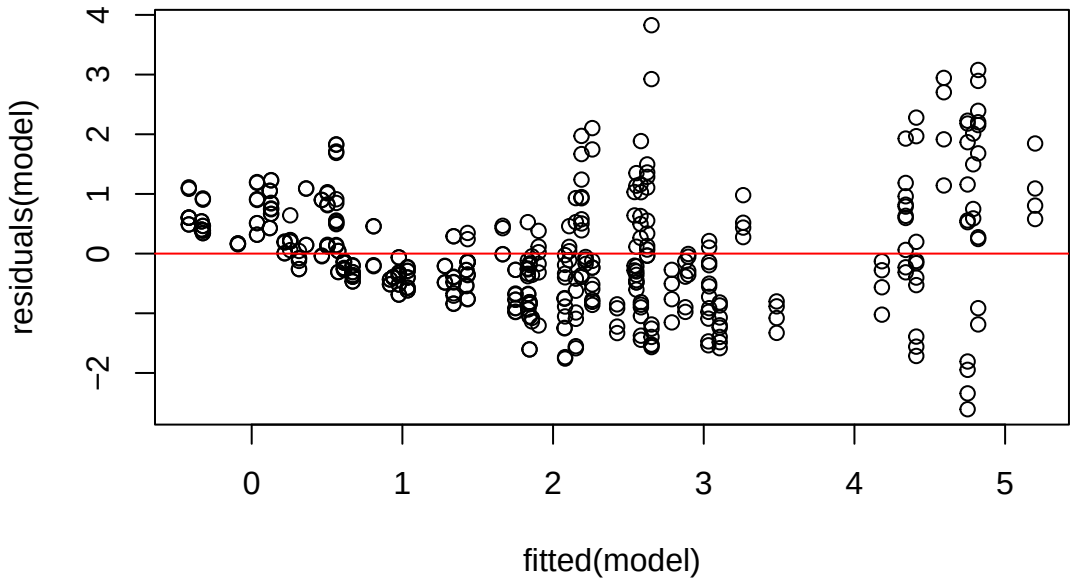
```
Type III Analysis of Variance Table with Satterthwaite's method
                          Sum Sq Mean Sq NumDF  DenDF  F value    Pr(>F)
tissu                     480.67 160.224     3 386.02 172.7160 < 2.2e-16 ***
treatment                   4.06   4.062     1   5.12   4.3784   0.08934 .
dayPeriod                   2.72   2.718     1 386.13   2.9302   0.08774 .
tissu:treatment            36.35  12.116     3 386.02  13.0608 3.848e-08 ***
tissu:dayPeriod             5.95   1.983     3 386.02   2.1380   0.09496 .
treatment:dayPeriod         0.16   0.156     1 386.33   0.1677   0.68235
tissu:treatment:dayPeriod   1.26   0.420     3 386.02   0.4530   0.71531
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

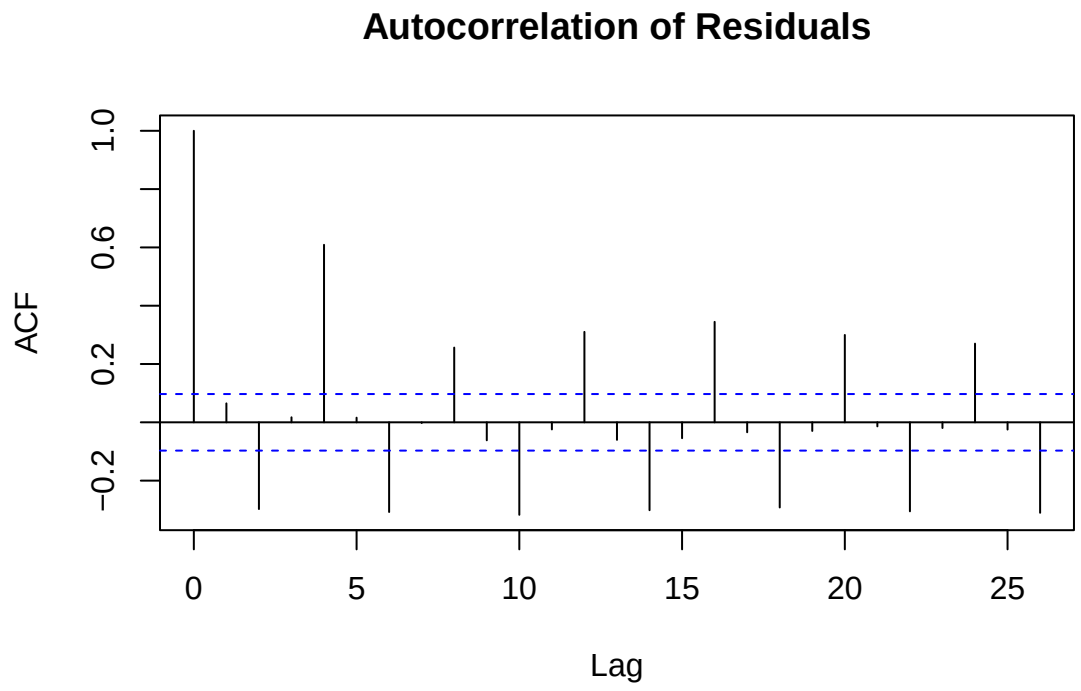
Checking assumption




```
    Shapiro-Wilk normality test
```

```
data:  residuals(model)
W = 0.97114, p-value = 3.211e-07
```





Model 3: Nested Model for DayPeriod and Time Effects In this model, dayPeriod is used as a broader time effect, with time nested within dayPeriod.

This model also includes campagne, sample, and chamber as random effects.

```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: StarchNscTissue ~ tissu + treatment + dayPeriod + dayPeriod:time +
    (1 | campagne) + (1 | sample) + (1 | chamber)
   Data: data

REML criterion at convergence: 1192.6

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.2829 -0.6858 -0.0363  0.4039  3.8747

Random effects:
 Groups   Name        Variance Std.Dev.
```

```
 chamber  (Intercept) 0.0276   0.1661
 sample   (Intercept) 0.2245   0.4738
 campagne (Intercept) 0.5451   0.7383
 Residual             1.0075   1.0037
Number of obs: 408, groups:  chamber, 8; sample, 8; campagne, 2

Fixed effects:
                     Estimate Std. Error        df t value Pr(>|t|)
(Intercept)           0.80373    0.59686   1.34648   1.347 0.360931
tissuIT               0.03626    0.14055 392.01679   0.258 0.796569
tissuLM               2.42265    0.14055 392.01679  17.237  < 2e-16 ***
tissuUM               2.26940    0.14055 392.01679  16.147  < 2e-16 ***
treatmentDrought     -0.77436    0.36888   5.01240  -2.099 0.089702 .
dayPeriodNight        0.36950    0.16284 392.08694   2.269 0.023804 *
dayPeriodDay:timeB    0.24285    0.16591 392.19489   1.464 0.144068
dayPeriodNight:timeC  0.04250    0.17744 392.01679   0.240 0.810825
dayPeriodDay:timeE    0.12013    0.16284 392.08694   0.738 0.461138
dayPeriodDay:timeF    0.62719    0.16591 392.19489   3.780 0.000181 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Correlation of Fixed Effects:
            (Intr) tissIT tissLM tissUM trtmnD dyPrdN dyPD:B dyPN:C dyPD:E
tissuIT     -0.118
tissuLM     -0.118  0.500
tissuUM     -0.118  0.500  0.500
trtmntDrght -0.309  0.000  0.000  0.000
dayPerdNght -0.111  0.000  0.000  0.000 -0.001
dyPrdDy:tmB -0.110  0.000  0.000  0.000  0.006  0.396
dyPrdNght:C  0.000  0.000  0.000  0.000  0.000 -0.545  0.000
dyPrdDy:tmE -0.111  0.000  0.000  0.000 -0.001  0.406  0.396  0.000
dyPrdDy:tmF -0.110  0.000  0.000  0.000  0.006  0.396  0.390  0.000  0.396
fit warnings:
fixed-effect model matrix is rank deficient so dropping 6 columns / coefficients

[1] 1220.641

[1] 1276.799

Type III Analysis of Variance Table with Satterthwaite's method
              Sum Sq Mean Sq NumDF  DenDF  F value    Pr(>F)
tissu         554.01 184.671     3 392.02 183.3018 < 2.2e-16 ***
```

```
treatment        4.44   4.440     1   5.01   4.4068  0.089702 .
dayPeriod        5.19   5.187     1 392.09   5.1489  0.023804 *
dayPeriod:time  15.20   3.801     4 392.11   3.7724  0.005036 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
    Shapiro-Wilk normality test

data:  residuals(model3)
W = 0.96174, p-value = 8.022e-09
```

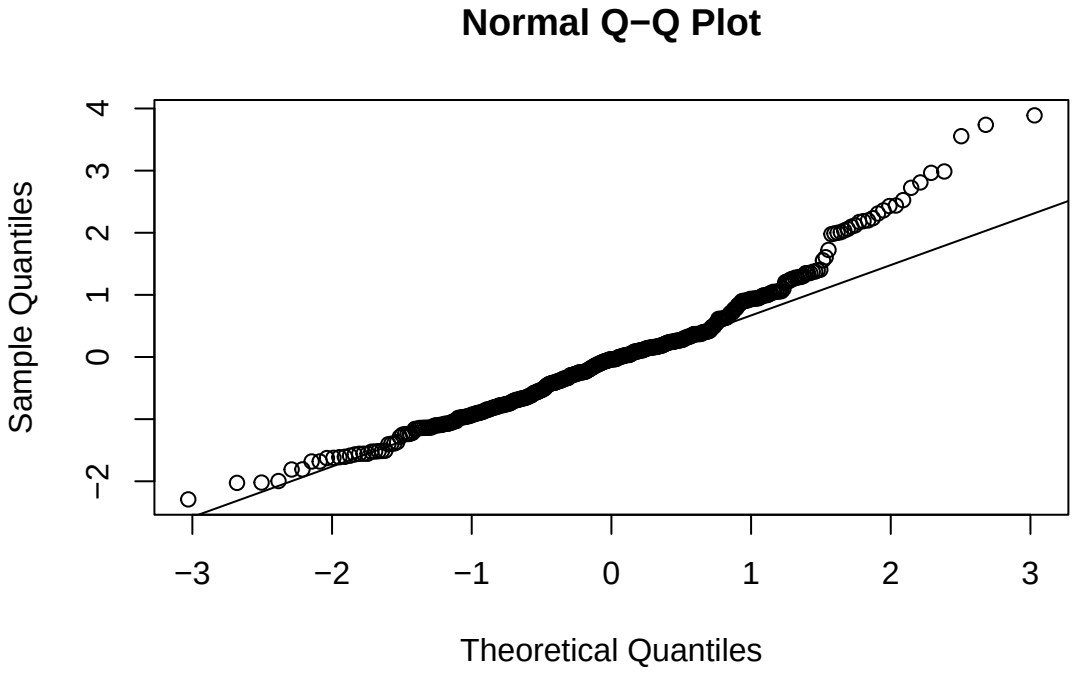


Figure 18

```
Call:
lm(formula = StarchNscTissue ~ treatment * tissu * dayPeriod +
    campagne, data = data)
```

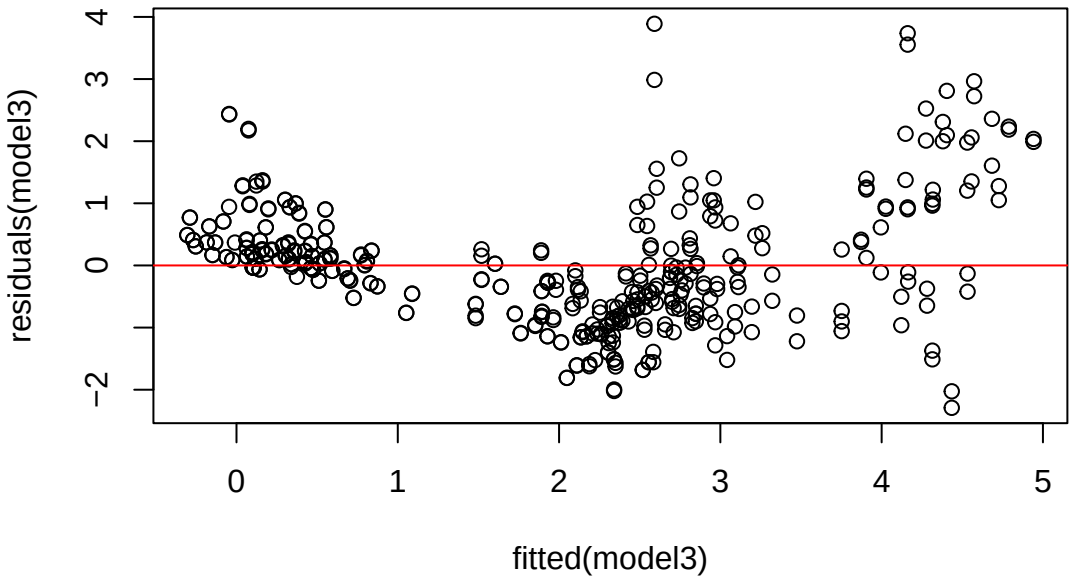


Figure 19

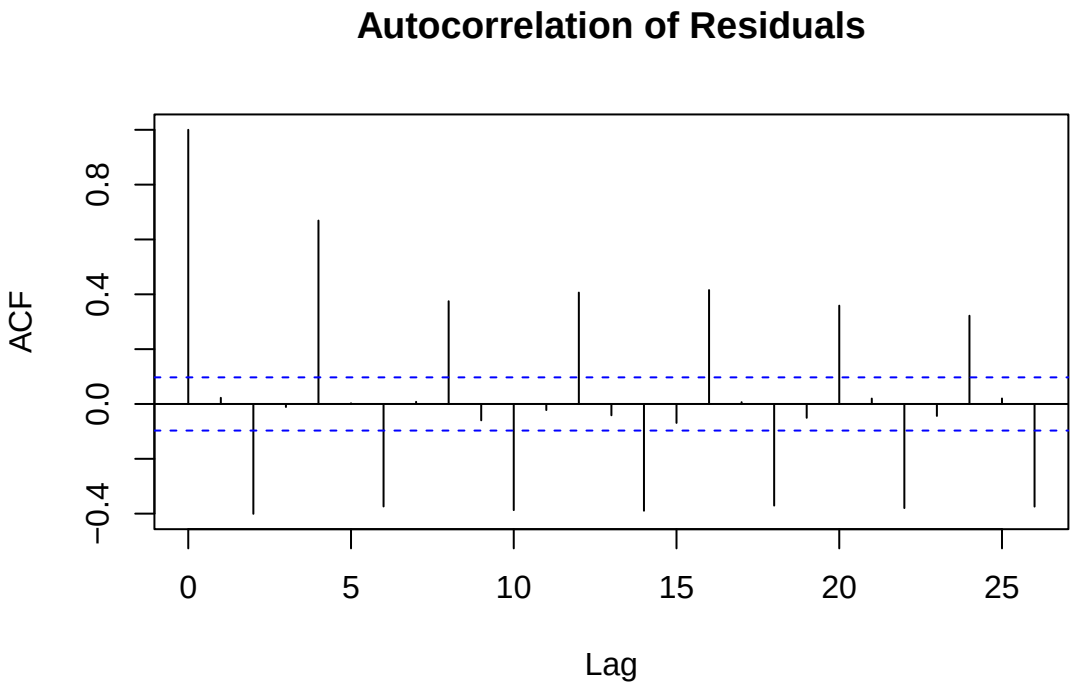
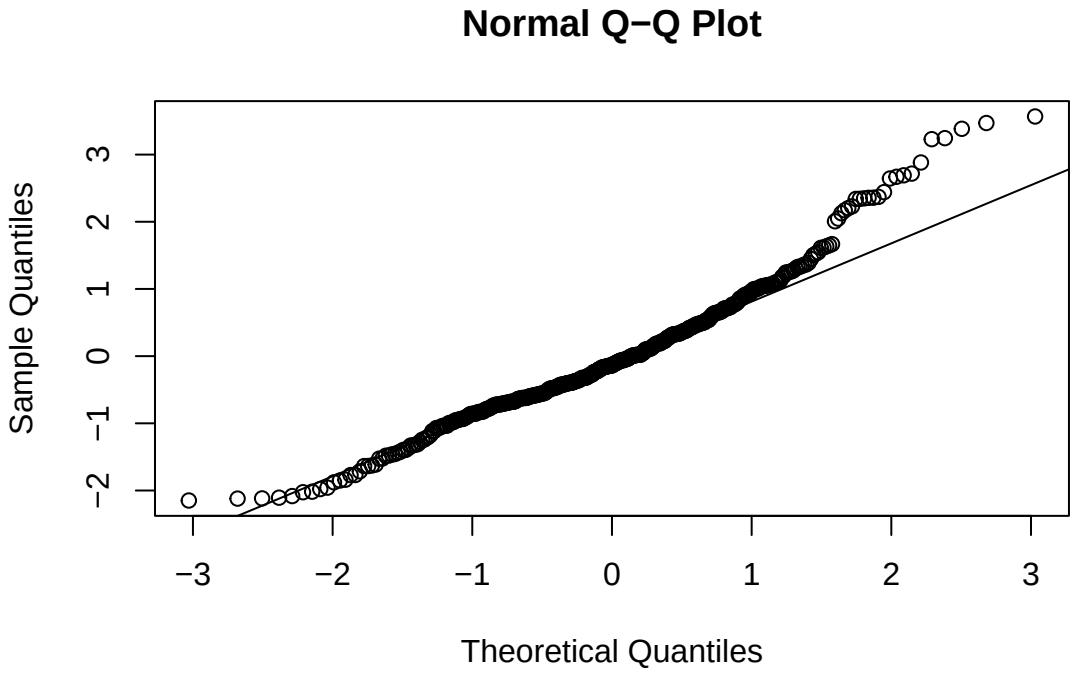

Autocorrelation of Residuals
ACF
0.8
0.4
0.0
−0.4
0
5
10
15
20
25
Lag

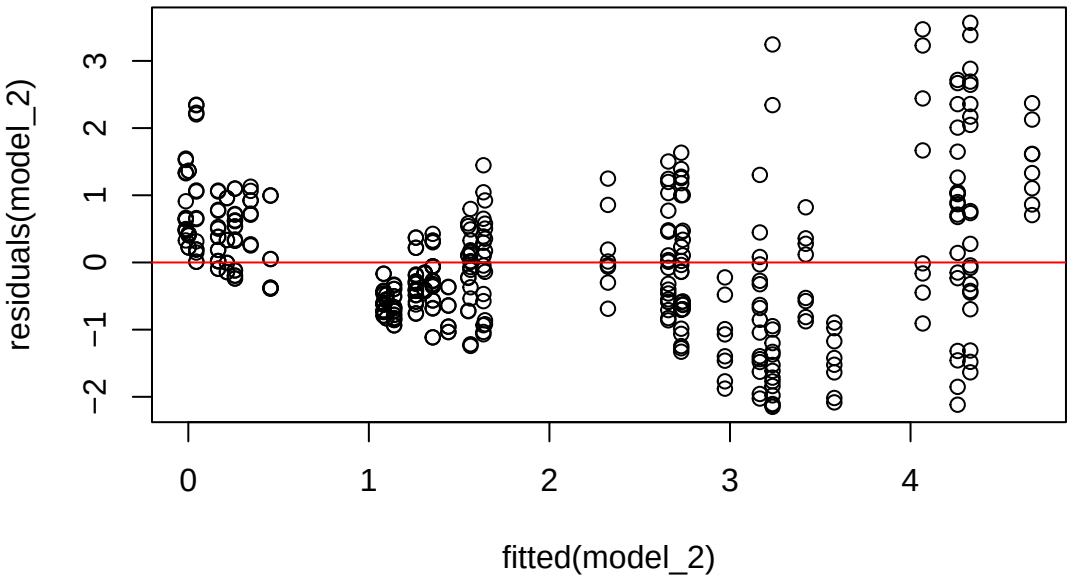
Figure 20

```
Residuals:
    Min      1Q  Median      3Q     Max
-2.1490 -0.6395 -0.1383  0.5298  3.5674

Coefficients:
                                          Estimate Std. Error t value Pr(>|t|)
(Intercept)                               -0.93022    0.23779  -3.912 0.000108
treatmentDrought                          -0.17885    0.24974  -0.716 0.474327
tissuIT                                    0.09316    0.24612   0.379 0.705243
tissuLM                                    3.00031    0.24612  12.190  < 2e-16
tissuUM                                    3.07044    0.24612  12.475  < 2e-16
dayPeriodNight                             0.04878    0.31380   0.155 0.876544
campagne                                   1.09540    0.10416  10.516  < 2e-16
treatmentDrought:tissuIT                  -0.03511    0.35315  -0.099 0.920866
treatmentDrought:tissuLM                  -1.42355    0.35315  -4.031 6.68e-05
treatmentDrought:tissuUM                  -1.42214    0.35315  -4.027 6.79e-05
treatmentDrought:dayPeriodNight            0.30988    0.44572   0.695 0.487317
tissuIT:dayPeriodNight                     0.14820    0.44370   0.334 0.738553
tissuLM:dayPeriodNight                     0.36356    0.44370   0.819 0.413066
tissuUM:dayPeriodNight                    -0.31235    0.44370  -0.704 0.481870
treatmentDrought:tissuIT:dayPeriodNight   -0.54948    0.63032  -0.872 0.383883
treatmentDrought:tissuLM:dayPeriodNight    0.03887    0.63032   0.062 0.950859
treatmentDrought:tissuUM:dayPeriodNight   -0.03772    0.63032  -0.060 0.952308

(Intercept)                               ***
treatmentDrought
tissuIT
tissuLM                                   ***
tissuUM                                   ***
dayPeriodNight
campagne                                  ***
treatmentDrought:tissuIT
treatmentDrought:tissuLM                  ***
treatmentDrought:tissuUM                  ***
treatmentDrought:dayPeriodNight
tissuIT:dayPeriodNight
tissuLM:dayPeriodNight
tissuUM:dayPeriodNight
treatmentDrought:tissuIT:dayPeriodNight
treatmentDrought:tissuLM:dayPeriodNight
treatmentDrought:tissuUM:dayPeriodNight
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Residual standard error: 1.044 on 391 degrees of freedom
Multiple R-squared:  0.6513,    Adjusted R-squared:  0.6371
F-statistic: 45.65 on 16 and 391 DF,  p-value: < 2.2e-16
```

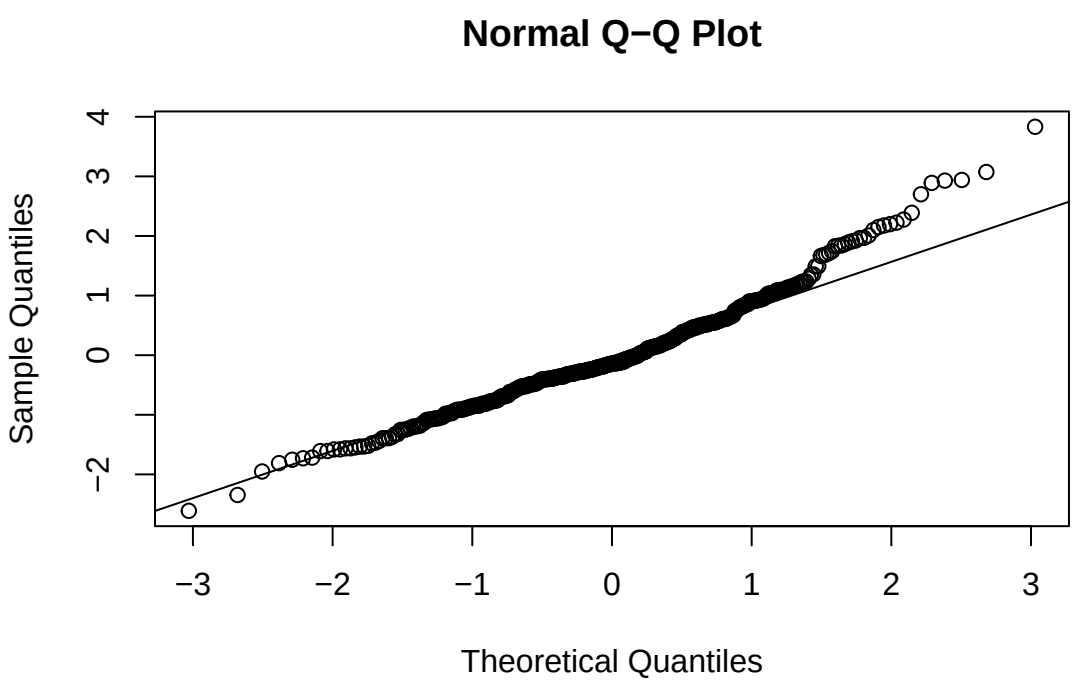



```
    Shapiro-Wilk normality test

data:  residuals(model_2)
W = 0.96501, p-value = 2.709e-08
```

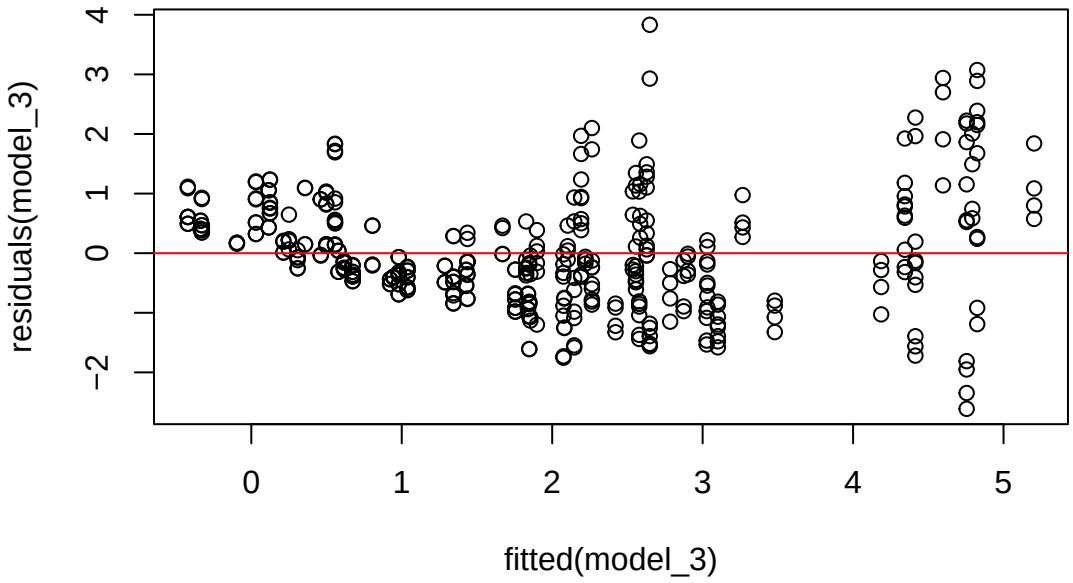



```
Linear mixed model fit by REML. t-tests use Satterthwaite's method [
lmerModLmerTest]
Formula: StarchNscTissue ~ treatment * tissu * dayPeriod + campagne +
    (1 | chamber)
   Data: data

REML criterion at convergence: 1148.9

Scaled residuals:
    Min      1Q  Median      3Q     Max
-2.7113 -0.5756 -0.1467  0.5350  3.9784

Random effects:
 Groups   Name        Variance Std.Dev.
 chamber  (Intercept) 0.2484   0.4984
 Residual             0.9277   0.9632
Number of obs: 408, groups:  chamber, 8

Fixed effects:
                                        Estimate Std. Error        df t value
```

```
(Intercept)                                -0.94922    0.62429   5.65354  -1.520
treatmentDrought                           -0.09081    0.42131   8.85361  -0.216
tissuIT                                     0.09316    0.22702 386.01184   0.410
tissuLM                                     3.00031    0.22702 386.01184  13.216
tissuUM                                     3.07044    0.22702 386.01184  13.525
dayPeriodNight                              0.08484    0.28949 386.02903   0.293
campagne                                    1.08403    0.36534   5.01449   2.967
treatmentDrought:tissuIT                   -0.03511    0.32574 386.01184  -0.108
treatmentDrought:tissuLM                   -1.42355    0.32574 386.01184  -4.370
treatmentDrought:tissuUM                   -1.42214    0.32574 386.01184  -4.366
treatmentDrought:dayPeriodNight             0.22184    0.41140 386.09222   0.539
tissuIT:dayPeriodNight                      0.14820    0.40926 386.01184   0.362
tissuLM:dayPeriodNight                      0.36356    0.40926 386.01184   0.888
tissuUM:dayPeriodNight                     -0.31235    0.40926 386.01184  -0.763
treatmentDrought:tissuIT:dayPeriodNight    -0.54948    0.58140 386.01184  -0.945
treatmentDrought:tissuLM:dayPeriodNight     0.03887    0.58140 386.01184   0.067
treatmentDrought:tissuUM:dayPeriodNight    -0.03772    0.58140 386.01184  -0.065
                                          Pr(>|t|)
(Intercept)                                 0.1822
treatmentDrought                            0.8342
tissuIT                                     0.6818
tissuLM                                   < 2e-16 ***
tissuUM                                   < 2e-16 ***
dayPeriodNight                              0.7696
campagne                                    0.0311 *
treatmentDrought:tissuIT                    0.9142
treatmentDrought:tissuLM                  1.60e-05 ***
treatmentDrought:tissuUM                  1.63e-05 ***
treatmentDrought:dayPeriodNight             0.5900
tissuIT:dayPeriodNight                      0.7175
tissuLM:dayPeriodNight                      0.3749
tissuUM:dayPeriodNight                      0.4458
treatmentDrought:tissuIT:dayPeriodNight     0.3452
treatmentDrought:tissuLM:dayPeriodNight     0.9467
treatmentDrought:tissuUM:dayPeriodNight     0.9483
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```




```
    Shapiro-Wilk normality test

data:  residuals(model_3)
W = 0.97131, p-value = 3.444e-07
```



Conclusion

GitHub page found here.

References

Astley, Rick. 1987. “Never Gonna GIve You Up.” 1987. https://r.mtdv.me/videos/6QMWR9vBma.

Appendix A - R Code

```r
## Prints code without running it

library(knitr)
data <- read.csv("data.csv")
knitr::kable(head(data), format = 'markdown')
```

Appendix B - SAS Code

```
data rptm_means;
input Inoculation_Method $ Thickness $ @@;
do Week=1 to 5 by 1;
    input mu @@;
    output;
end;
datalines;
Dry 1/4 4.2573 4.246 4.474 4.3327 4.0127
Dry 1/8 5.2907 4.9513 5.2013 5.2073 4.9713
Wet 1/4 5.4013 5.5727 5.55 5.4873 5.3807
Wet 1/8 5.56 5.7793 5.6313 5.7153 5.62
;
```