

## 2.3 Mathematical Models Development

In case of persimmon disk and cube, regression analysis was used to fit the mass transfer parameters ( $D_{ew}$  and  $D_{es}$ ) with the concentrations of sucrose and NaCl. For the whole fruit, the response variables,  $WR$ ,  $WL$ ,  $SG$  and  $WL/SG$ , determined after 6, 12, 24, 36 and 48 h of immersion in the osmotic medium, for all treatment conditions, were analyzed using the regression method. A quadratic model was chosen for the description of the response variables to the factor variables: sucrose and NaCl concentrations. The regression validity was checked by estimating the determination coefficient  $R^2$ , standard error of estimate ( $S.E.$ ) and the associated  $P$ -value. The fitted quadratic equations were also expressed as contour plots in order to visualize the relationship between the response and factor levels.

### 2.3.1 For Persimmon Disk

#### 2.3.1.1 Regression Analysis for Persimmon Disk

The linear, quadratic and interaction effects for the 2<sup>nd</sup> order polynomial model involving the osmotic solution concentrations are given in Table 6, together with the goodness of fit ( $R^2$  and  $S.E.$ ) and model significance ( $P$ -value). The statistical analysis shows that the models gives satisfactory values of  $R^2$ , and all models are adequate at  $P < 0.05$  level. In all cases, both sucrose and NaCl concentrations were significant factors appearing within linear, quadratic and interaction effects except for  $D_{ew}$  where the quadratic effect of sucrose concentration was not significant. However, NaCl concentration influences linearity and quadratic terms significantly. This implies that mass transfer parameters are more sensitive to variations in NaCl concentration than sucrose. The low water activity of NaCl can increase the driving force for dehydration, and the low molecular weight of NaCl also allows a high rate of penetration into the material. For the same incremental increase in concentration, NaCl causes a significantly higher change in osmotic pressure than sucrose. Hence, a small amount of NaCl added to sucrose can enhance the diffusion process for dehydration significantly, thus justifying the use of ternary solutions.

**Table 6** Values of regression coefficients,  $R^2$ ,  $S.E.$ , and  $P$ -value for the 2<sup>nd</sup> order polynomials by persimmon disk.

<b>Coefficients</b>	$D_{ew} \times 10^{10}$	$D_{es} \times 10^{10}$
$\beta_0$	0.4757	3.538
<b>Linear</b>		
$\beta_1$	0.0370	-0.0765
$\beta_2$	0.0444	-0.5164
<b>Quadratic</b>		
$\beta_{11}$	NS	0.0006
$\beta_{22}$	0.0053	0.0194
<b>Interaction</b>		
$\beta_{12}$	0.0005	0.0114
$R^2$	0.928	0.799
$S.E.$	0.079	0.262
$P$ -value	0.0007	0.0220

NS: non-significant ( $P > 0.05$ )

### 2.3.1.2 Response Surface Methodology for Persimmon Disk

Response surface methodology was used to visualize the relationship between experimental and response levels. The surface plots for  $D_{ew}$  and  $D_{es}$  as a function of sucrose and NaCl concentrations are shown in Figures 43 - 44, respectively. The effect of solute concentration on  $D_{ew}$  is shown in Figure 43. Increases in sucrose and NaCl concentrations result in increase in  $D_{ew}$ . However, NaCl appears to have a stronger influence than sucrose. It has been reported that high sucrose concentration may not promote further water diffusion from fruits and vegetables because the increase in solution viscosity can affect water migration (Lenart and Flink, 1984). Sankat, *et al.* (1996) stated that incorporation of sugar in starchy materials generally decreases the diffusivity because of the decrease in porosity of the materials. Moreover, high concentration of sucrose allows the

formation of a surface layer of sugar which acts as a barrier for the removal of water. Figure 44 illustrates the response surface contour plot of  $D_{es}$ . It clearly shows that high  $D_{es}$  values are obtained when high concentrations of sucrose and NaCl are used. Due to the different molecular dimensions, the sucrose tends to remain mainly in the extra cellular space while NaCl penetrates into the cell more easily: thus the higher the level of NaCl, the greater is the solute diffusion into the fruit.  $D_{ew}$  and  $D_{es}$  depend on the osmotic pressure gradient, which in turn depends on the concentration of sucrose and NaCl in the osmotic solution. The results relating to  $D_{ew}$  and  $D_{es}$  indicate that higher concentration solutions, yield benefits in terms of greater  $D_{ew}$ ; however,  $D_{es}$  is also much greater.

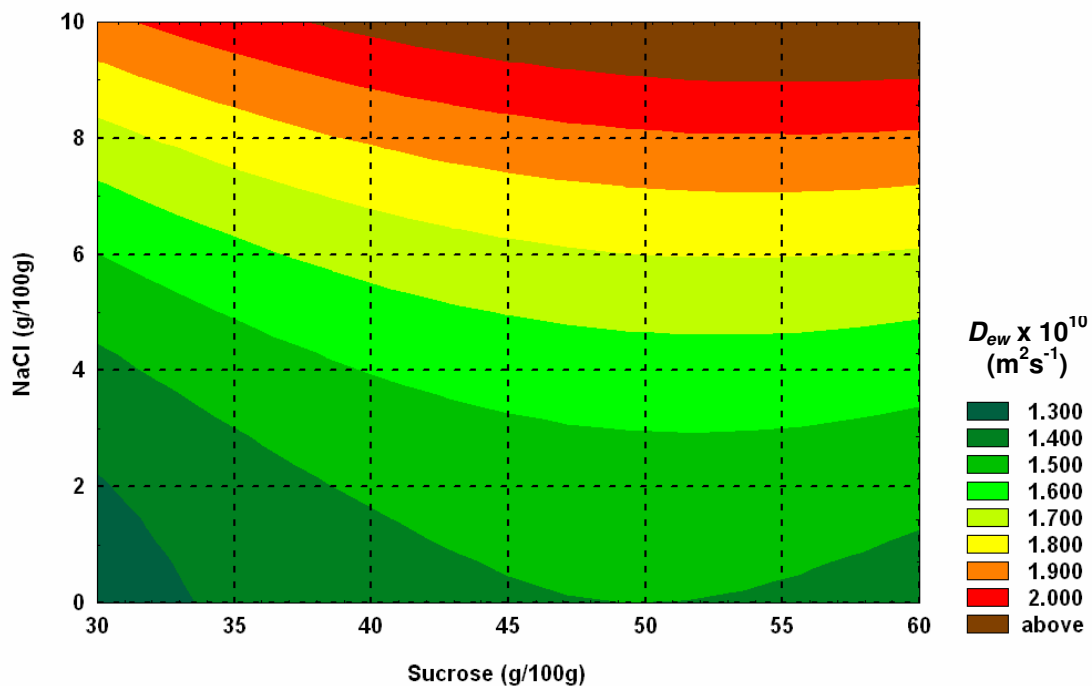


Figure 43 Response surface for  $D_{ew}$  as functions of sucrose and NaCl by disks.

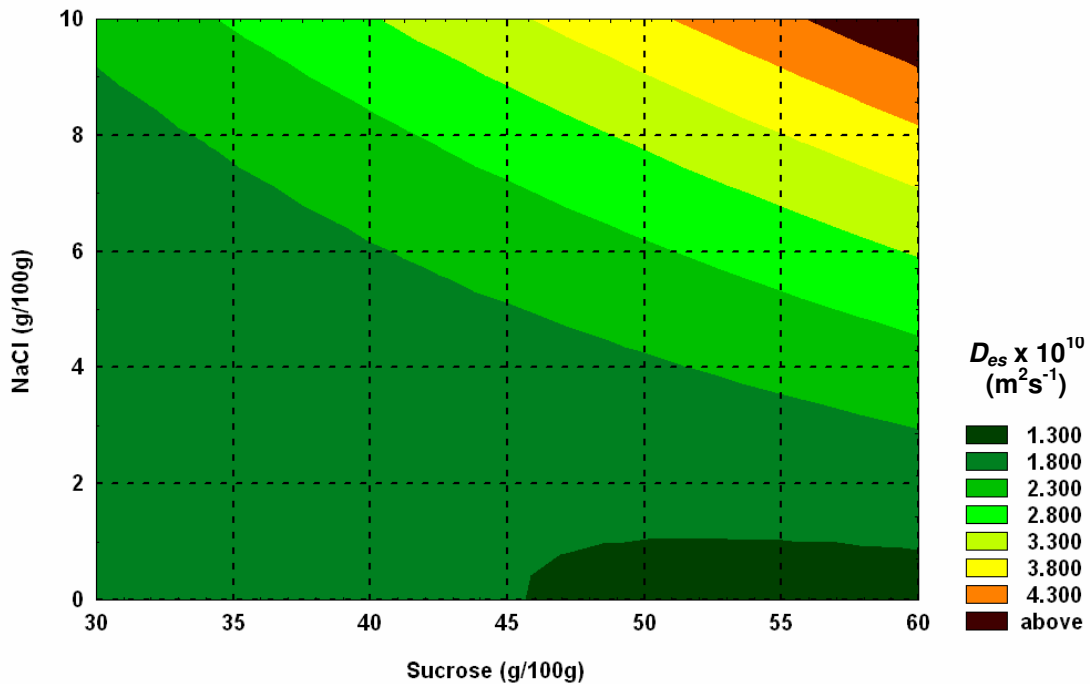


Figure 44 Response surface for  $D_{es}$  as functions of sucrose and NaCl by disks.

### 2.3.2 For Persimmon Cube

#### 2.3.2.1 Regression Analysis for Persimmon Cube

The model performance was evaluated by the goodness of fit values ( $R^2$  and  $S.E.$ ) and model significance ( $P$ -value), as shown in Table 7. The statistical analysis shows that the models give satisfactory values of  $R^2$ , and all models are adequate at  $P < 0.05$  level. According to Table 7, the coefficient effects for the 2<sup>nd</sup> order polynomial model involving the osmotic solution concentrations are shown. In all the cases, both sucrose and NaCl concentrations were significant factors appearing within linear, quadratic and interaction effects except for  $D_{ew}$  where the quadratic effect of NaCl concentration was not significant.

**Table 7** Values of regression coefficients,  $R^2$ ,  $S.E.$ , and  $P$ -value for the 2<sup>nd</sup> order polynomials by persimmon cube.

<b>coefficients</b>	$D_{ew} \times 10^{10}$	$D_{es} \times 10^{13}$
$\beta_0$	1.081	-6.438
<b>Linear</b>		
$\beta_1$	0.061	0.315
$\beta_2$	0.064	0.441
<b>Quadratic</b>		
$\beta_{11}$	-0.001	-0.003
$\beta_{22}$	NS	-0.003
<b>Interaction</b>		
$\beta_{12}$	3.347E-5	-0.004
$R^2$	0.9150	0.8923
$S.E.$	0.0896	0.0004
$P$ -value	0.0013	0.0028

NS: non-significant ( $P > 0.05$ )

### 2.3.2.2 Response Surface Methodology for Persimmon Cube

The response surface plots for  $D_{ew}$  and  $D_{es}$  as a function of sucrose and NaCl concentrations are shown in Figures 45 - 46, respectively. The effect of solute concentration on  $D_{ew}$  is shown in Figure 45. It was found that high  $D_{ew}$  values are obtained when high concentrations of sucrose and NaCl are used. However, it is clearly seen that  $D_{ew}$  decreased when higher concentrations of sucrose (from 50 to 60 g/100g) were combined with low NaCl concentrations (from 0 to 3.5 g/100g). As mention earlier, further water diffusion from fruits may not occur at high sucrose concentration as also sucrose allows the formation of a surface layer of sugar which acts as a barrier for the removal of water. Moreover, a very small amount of NaCl added to this osmotic solution can not enhance the diffusion process for further water removal. Figure 46 shows the response surface contour plot of  $D_{es}$ . It was found that

high  $D_{es}$  values are obtained when high concentrations of NaCl are used. Since NaCl penetrates into the cell more easily, the higher the level of NaCl, the greater is the solute diffusion into the fruit. Higher concentrations of NaCl led to increase in solid gain, probably due to the increase in osmotic pressure gradient and consequent loss of functionality of the cell plasmatic membrane which facilitated solute entry.  $D_{ew}$  and  $D_{es}$  depended on the concentration of sucrose and NaCl in the osmotic solution. The results relating to  $D_{ew}$  and  $D_{es}$  indicated that the higher concentration solutions of sucrose and NaCl can gave greater values of  $D_{ew}$  and  $D_{es}$ . However, in fact the criteria for constraints optimization are higher  $D_{ew}$  and lower  $D_{es}$

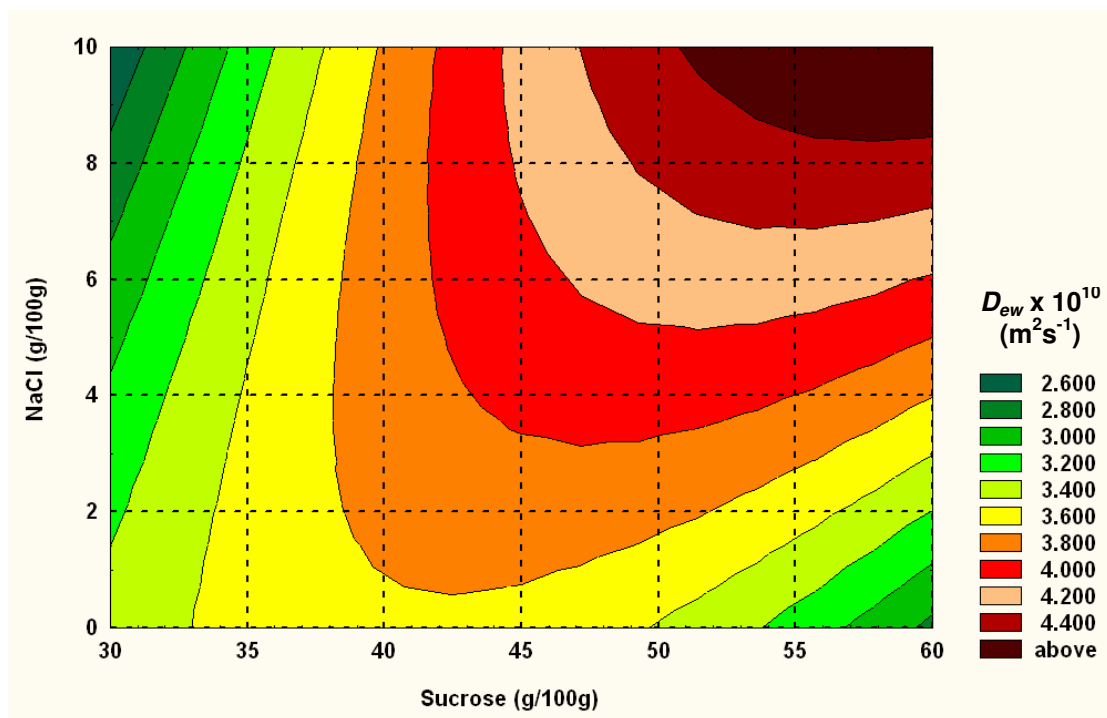


Figure 45 Response surface for  $D_{ew}$  as functions of sucrose and NaCl by cubes.

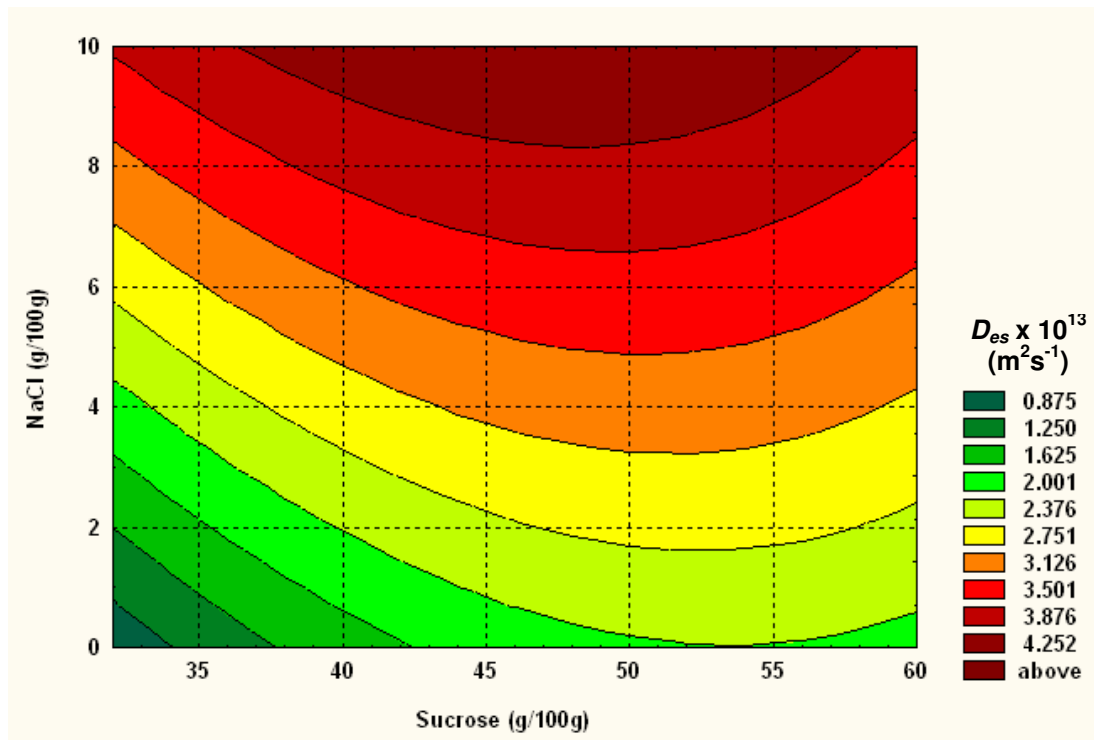


Figure 46 Response surface for  $D_{es}$  as functions of sucrose and NaCl by cubes.

### 2.3.3 Osmotic Dehydration of the Whole Fruit

#### 2.3.3.1 Regression Analysis for Whole Fruit

Regression analysis was used to fit the mass transfer attributes ( $WR$ ,  $SG$  and  $WL$ ) for each immersion time with the concentrations of sucrose and NaCl. The linear, quadratic and interactive effects for the quadratic model involving the osmotic solution concentrations are given, together with the goodness of fit ( $R^2$  and  $S.E.$ ) and model significance ( $P$ -value) as shown in Tables 8-12. The statistical analysis shows that all models give satisfactory values of  $R^2$ , and all models are adequate at  $P < 0.05$  level. Statistical analysis also shows that the coefficient of the linear terms in sucrose and NaCl concentrations are positive for the attributes  $WR$  and  $WL$  ( $P < 0.05$ ) when immersion times are: 6, 12, 24, 36 and 48 h. The expressions for  $WR$  and  $WL$  are characterized by strong linear terms in osmotic solution concentrations. An increase in concentration results in an increase in osmotic pressure gradient (and hence a decrease in the water activity), this increases the driving force

for water removal between solution and food, and causes higher mass transfer rates and weight reduction. In the case of *SG*, for immersion times of 6, 12 and 24 h, sucrose and NaCl concentrations have positive coefficients for the linear terms, but the coefficients become negative for higher immersion times of 36 and 48 h. This implies that the rate of solid gain is increases with the solute concentrations for the first 24 hours of the process, and then drops at longer times. The rapid solid gain in the beginning is apparently due to the large osmotic driving force between the dilute sap of the fresh fruit and the hypertonic solution. From Table 9-13, the coefficients of the second degree terms in sucrose and NaCl concentrations in most of the cases have marginal effects on *WR*, *WL* and *SG*. Moreover, some terms were not significant. Additionally, the interaction term (i.e. product of sucrose and NaCl concentrations) was always insignificant. Thus, the mass transfer attributes of *WR*, *WL* and *SG* are simple functions of sucrose and NaCl concentrations.

**Table 8** Values of regression coefficients,  $R^2$ , *S.E.*, and *P-value* for the 2<sup>nd</sup> order polynomials of 6 hr immersion time by whole fruit

<b>Coefficients</b>	<b><i>WR</i></b>	<b><i>WL</i></b>	<b><i>SG</i></b>	<b><i>WL/SG</i></b>
$\beta_0$	-0.2912	-0.208	0.109	-5.823
<b>Linear</b>				
$\beta_1$	0.0247	0.022	0.003	0.660
$\beta_2$	0.0061	0.006	0.002	-0.229
<b>Quadratic</b>				
$\beta_{11}$	-0.0002	NS	4.205E-5	-0.007
$\beta_{22}$	0.0002	3.642E-5	-9.086E-5	0.021
<b>Interaction</b>				
$\beta_{12}$	-0.0001	1.078E-7	N S	-0.007
<b><math>R^2</math></b>	0.8122	0.961	0.830	0.828
<b><i>S.E.</i></b>	0.00379	0.061	0.0004	0.076
<b><i>P-value</i></b>	0.01651	0.0001	0.0128	0.0009

NS: non-significant ( $P>0.05$ )

**Table 9** Values of regression coefficients,  $R^2$ ,  $S.E.$ , and  $P$ -value for the 2<sup>nd</sup> order polynomials of 12 hr immersion time by whole fruit

<b>Coefficients</b>	<b>WR</b>	<b>WL</b>	<b>SG</b>	<b>WL/SG</b>
$\beta_0$	-0.1384	-0.065	0.076	4.652
<b>Linear</b>				
$\beta_1$	0.0251	0.023	0.002	0.310
$\beta_2$	0.0016	0.1754	0.002	-0.582
<b>Quadratic</b>				
$\beta_{11}$	-0.0003	NS	3.784E-5	-0.005
$\beta_{22}$	0.0006	0.001	NS	0.016
<b>Interaction</b>				
$\beta_{12}$	0.0003	NS	9.346E-5	0.005
<b><math>R^2</math></b>	0.7184	0.961	0.830	0.907
<b><math>S.E.</math></b>	0.0229	0.061	0.0004	0.065
<b><math>P</math>-value</b>	0.0636	0.0001	0.0128	0.0004

NS: non-significant ( $P>0.05$ )

Table 10 Values of regression coefficients,  $R^2$ ,  $S.E.$ , and  $P$ -value for the 2<sup>nd</sup> order polynomials of 24 hr immersion time by whole fruit

<b>Coefficients</b>	<b>WR</b>	<b>WL</b>	<b>SG</b>	<b>WL/SG</b>
$\beta_0$	-0.0622	0.125	0.199	-2.612
<b>Linear</b>				
$\beta_1$	0.0206	0.014	0.007	0.583
$\beta_2$	0.0045	0.001	0.006	-0.094
<b>Quadratic</b>				
$\beta_{11}$	-0.0002	NS	9.458E-5	-0.008
$\beta_{22}$	0.0004	NS	NS	-0.013
<b>Interaction</b>				
$\beta_{12}$	0.0001	NS	NS	0.001
<b><math>R^2</math></b>	0.8117	0.961	0.830	0.981
<b><math>S.E.</math></b>	0.0189	0.061	0.0004	0.021
<b><math>P</math>-value</b>	0.0177	0.0001	0.0128	0.0008

NS: non-significant ( $P>0.05$ )

**Table 11** Values of regression coefficients,  $R^2$ ,  $S.E.$ , and  $P$ -value for the 2<sup>nd</sup> order polynomials of 36 hr immersion time by whole fruit

<b>Coefficients</b>	<b>WR</b>	<b>WL</b>	<b>SG</b>	<b>WL/SG</b>
$\beta_0$	0.2395	0.328	0.083	3.909
<b>Linear</b>				
$\beta_1$	0.0022	0.005	-0.003	0.144
$\beta_2$	0.0181	0.017	-0.001	-0.573
<b>Quadratic</b>				
$\beta_{11}$	-2.6510E-5	-6.558E-5	-3.648E-5	-0.002
$\beta_{22}$	0.0005	NS	NS	0.031
<b>Interaction</b>				
$\beta_{12}$	0.0004	NS	5.966E-5	0.004
<b><math>R^2</math></b>	0.8353	0.961	0.830	0.911
<b><math>S.E.</math></b>	0.0128	0.061	0.0004	0.091
<b><math>P</math>-value</b>	0.0115	0.0001	0.0128	0.0004

NS: non-significant ( $P>0.05$ )

**Table 12** Values of regression coefficients,  $R^2$ ,  $S.E.$ , and  $P$ -value for the 2<sup>nd</sup> order polynomials of 48 hr immersion time by whole fruit

<b>Coefficients</b>	<b>WR</b>	<b>WL</b>	<b>SG</b>	<b>WL/SG</b>
$\beta_0$	0.0611	0.027	-0.019	11.528
<b>Linear</b>				
$\beta_1$	0.0043	0.006	-0.001	-0.161
$\beta_2$	0.0133	0.009	-0.004	-0.721
<b>Quadratic</b>				
$\beta_{11}$	-4.7395E-5	-5.994E-5	-5.619E-6	0.001
$\beta_{22}$	5.4631E-5	NS	NS	0.021
<b>Interaction</b>				
$\beta_{12}$	0.0004	NS	1.017E-5	0.01
$R^2$	0.9068	0.961	0.830	0.928
$S.E.$	0.0094	0.061	0.0004	0.079
$P$ -value	0.0017	0.0001	0.0128	0.0007

NS: non-significant ( $P>0.05$ )

### 2.3.3.2 Response Surface Methodology for Whole Fruit

Response surface methodology was used to visualize the relationship between experimental and response levels. The response surface contour plots for *WR*, *WL* and *SG* at 6, 12, 24, 36 and 48 h as a function of sucrose and NaCl concentrations are shown in Figures 45 - 64, respectively.

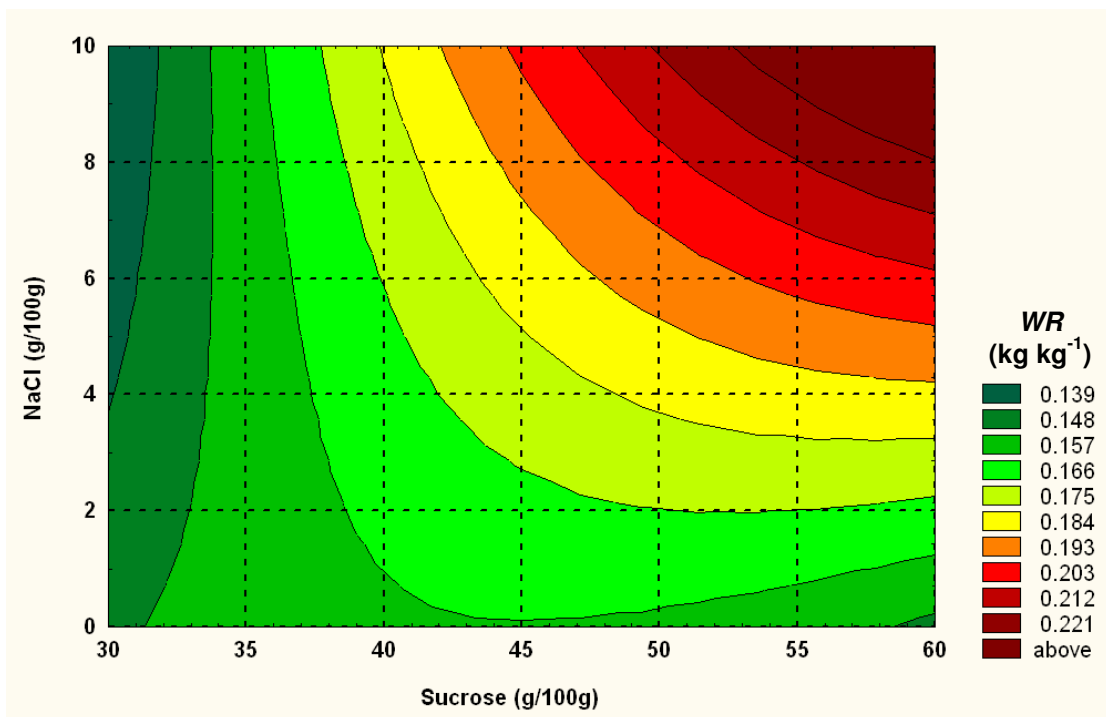
The relationship of *WR* with sucrose and NaCl concentrations at 6, 12, 24, 36 and 48 h are shown in Figures 47 – 51, respectively. All plots show similar trend where *WR* increased with sucrose and NaCl concentrations. Higher *WR* values were observed at high sucrose and NaCl concentrations for all the immersion times studied. Figures 52 - 56 illustrate the response surface contour plots of *WL* which show that *WL* rapidly increased with sucrose and NaCl concentration. Sucrose and NaCl were shown to have a synergistic

effect on water removal. The lower water activity of sucrose and NaCl combination increases the driving force for dehydration. However, NaCl causes a significantly higher change in osmotic pressure than sucrose. Isse and Schubert (1991) reported that at the cellular level, sucrose and NaCl can both pass through the cellular membrane while only NaCl can diffuse through cytoplasmic membrane. NaCl produces concentration gradients at the vacuole level and in the cytoplasm, thus allowing transfer of more water from deep inside the cell. However, it can be noted from the relationship of *WL* with sucrose and NaCl concentrations at long immersion time (36 h) in Figures 55 that *WL* tend to decreased with increasing sucrose concentration above 50 g/100g. This may be due to at high concentration of sucrose can make crusting as a barrier to water transfer at the surface of the cytoplasm. Further, the deposition of a higher level of sucrose in the material can also hinder water loss because of the decrease in porosity of the materials (Lenart and Flink, 1984).

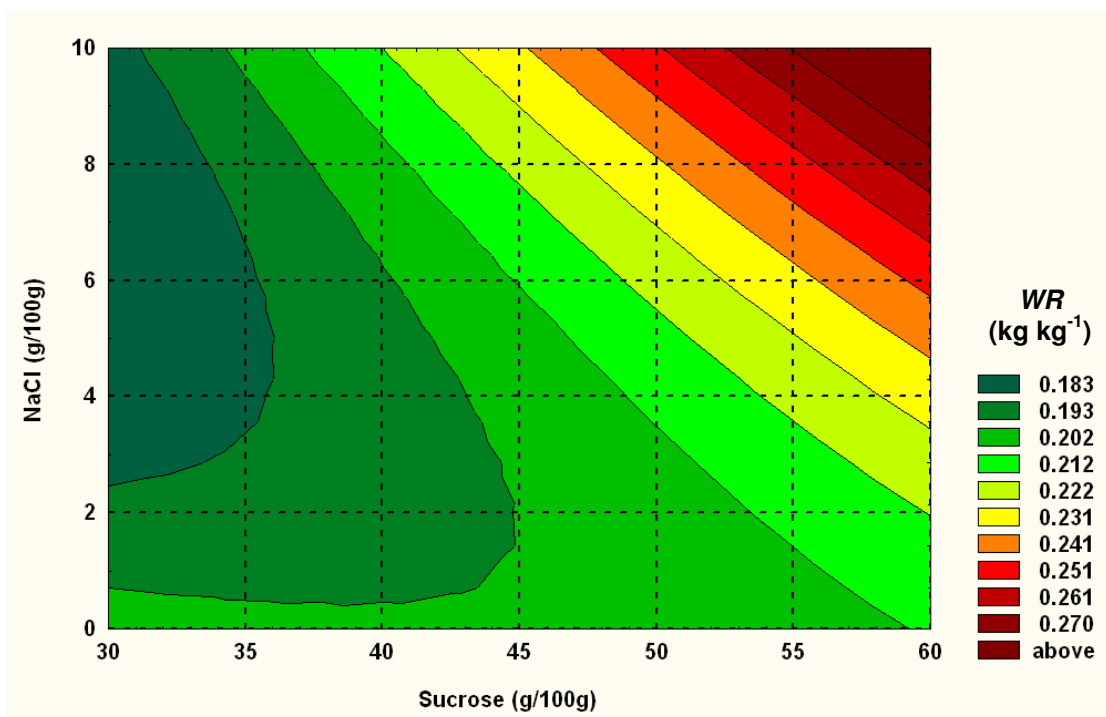
The effect of sucrose and NaCl concentration on *SG* is shown in Figures 57 - 61. At low sucrose concentrations (up to 35 g/100g), addition of NaCl marginally increases *SG*. In general *SG* increases with sucrose and NaCl concentrations for all immersion times. Use of NaCl leads to increase in solid gain, probably due to the increase in osmotic pressure gradient and consequent loss of functionality of the cell plasmatic membrane which facilitates solute entry. In fact, sucrose uptake shows similar behavior to NaCl uptake however with lower penetration rates.

The response surface methodology has been widely and effectively used for optimization during process development and/or improvement of product quality. The researcher can explore the process under study and come into regions showing maxima or minima. To evaluate the optimum conditions for an osmotic treatment in terms of mass transfer, the water loss and solid gain can be effective. Since low *SG* and high *WL* did not fall exactly in the same region (Figures 52 - 61), the ratio *WL/SG* was considered to be a good indicator of the extent to which the process achieves the minimization of solid gain and maximization of water loss;

this term has been used by several authors (Lazarides *et al*, 1996; Ravindra and Chattopadhyay, 2000). The regression equation describing the effect of sucrose and NaCl concentrations on the *WL/SG* for various immersion times are given in Tables 8 - 12, together with  $R^2$ , *S.E.* and *P-value*.  $R^2$  ranged between 0.828 and 0.981 which indicated that a high proportion of variability in response values can be explained or accounted for by the model; the good fit was also reinforced by the low value of *S.E.*(0.021- 0.091) and *P-value* lower than 0.05. Contours plot for variation of *WL/SG* as a function of sucrose and NaCl concentration for all immersion times: 6, 12, 24, 36 and 48 h, are shown in Figures 62 - 66. The contour plots at each immersion time shown the region of the maximum *WL/SG* values which are obtained using different combinations of sucrose and NaCl concentrations. A combination of optimum working conditions can be selected from the regions. Nevertheless the final decision of the best condition depend on considerations of the effects in others factors such as the physical, sensory characteristics of the osmosed product and its cost.



**Figure 47** Response surface for  $WR$  as functions of sucrose and NaCl concentration (whole fruit immersed for 6 h).



**Figure 48** Response surface for  $WR$  as functions of sucrose and NaCl concentration (whole fruit immersed for 12 h).

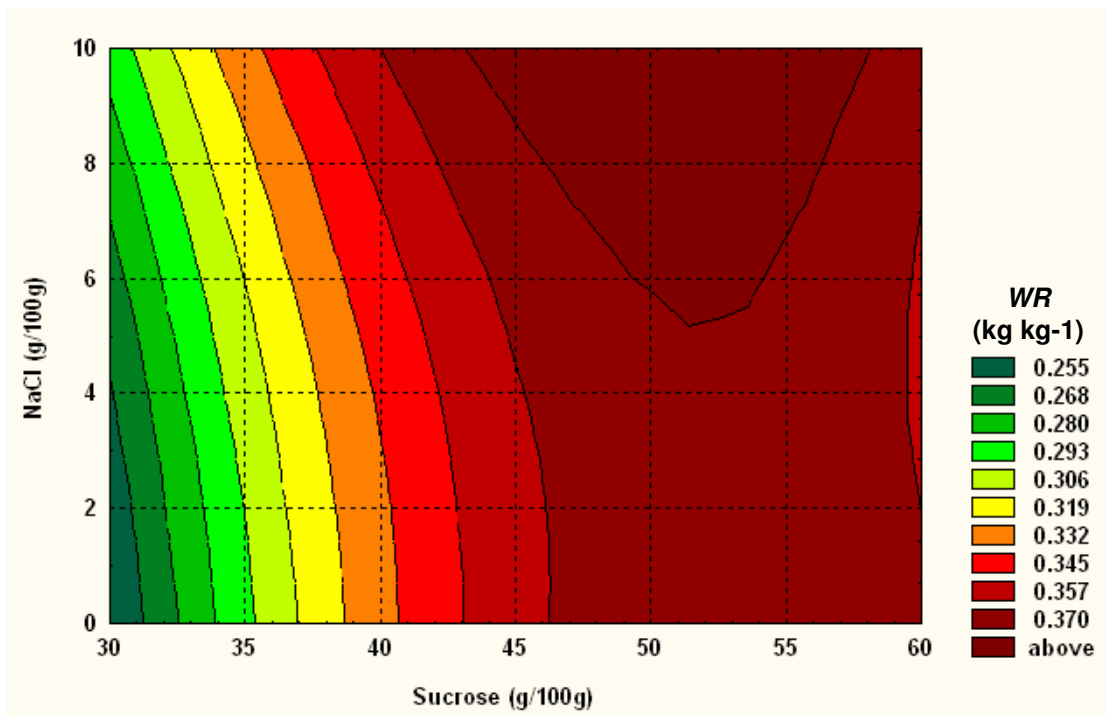


Figure 49 Response surface for  $WR$  as functions of sucrose and NaCl concentration (whole fruit immersed for 24 h).

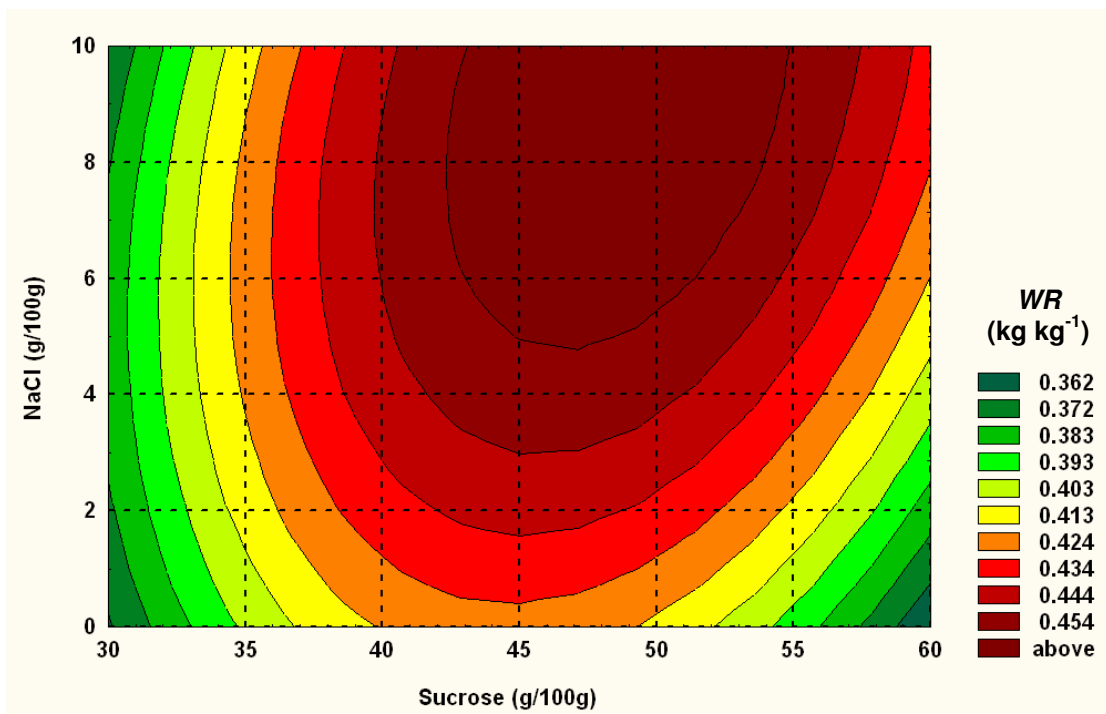


Figure 50 Response surface for  $WR$  as functions of sucrose and NaCl concentration (whole fruit immersed for 36 h).

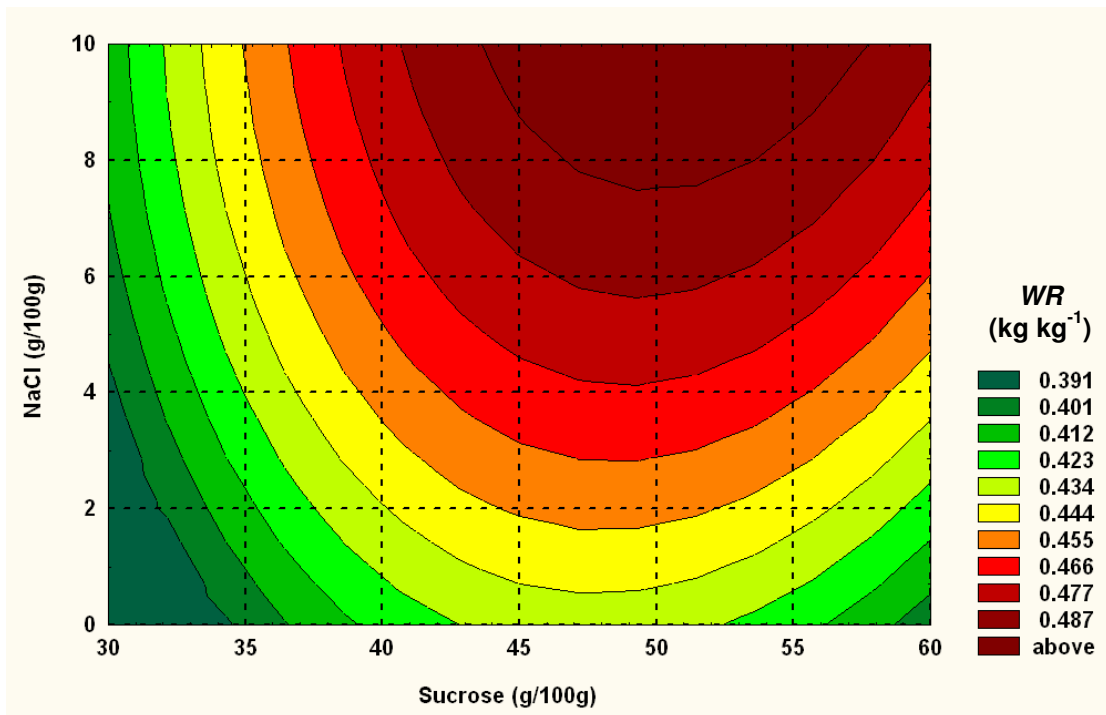


Figure 51 Response surface for  $WR$  as functions of sucrose and NaCl concentration (whole fruit immersed for 48 h).

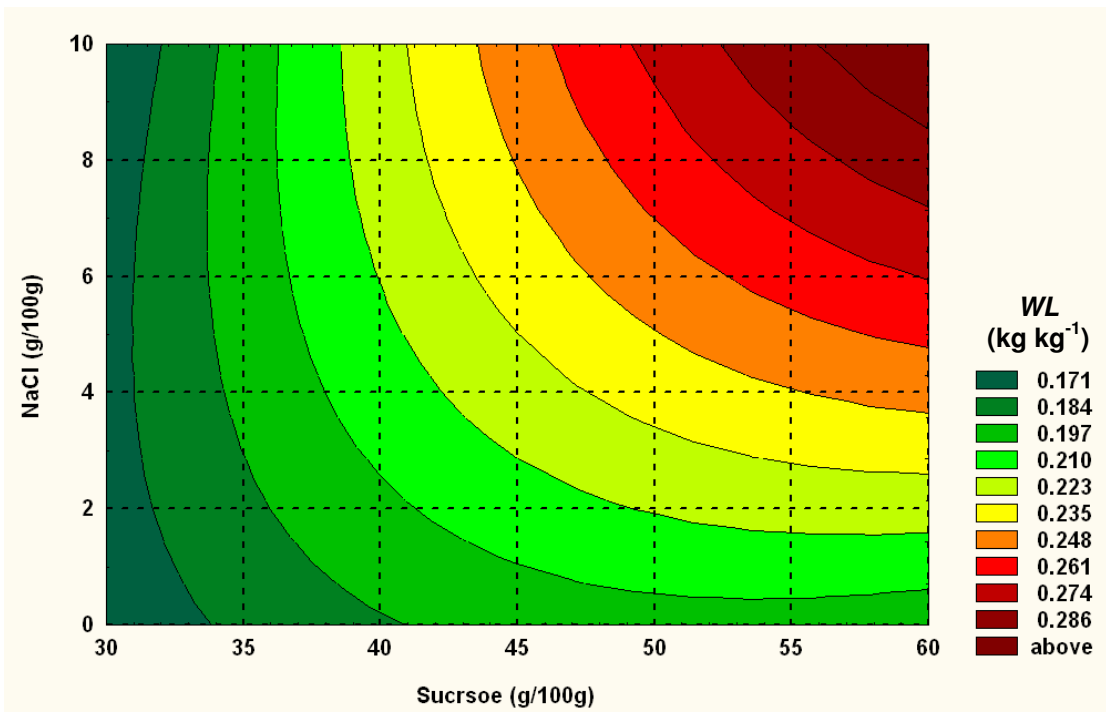


Figure 52 Response surface for  $WL$  as functions of sucrose and NaCl concentration (whole fruit immersed for 6 h).

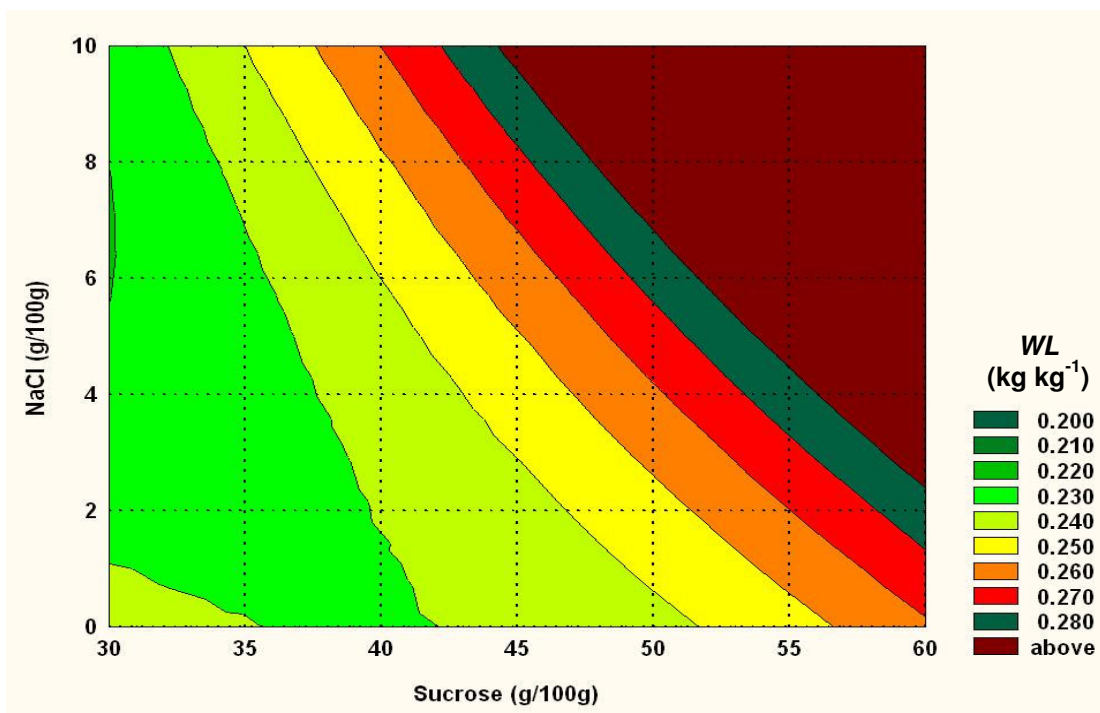


Figure 53 Response surface for *WL* as functions of sucrose and NaCl concentration (whole fruit immersed for 12 h).

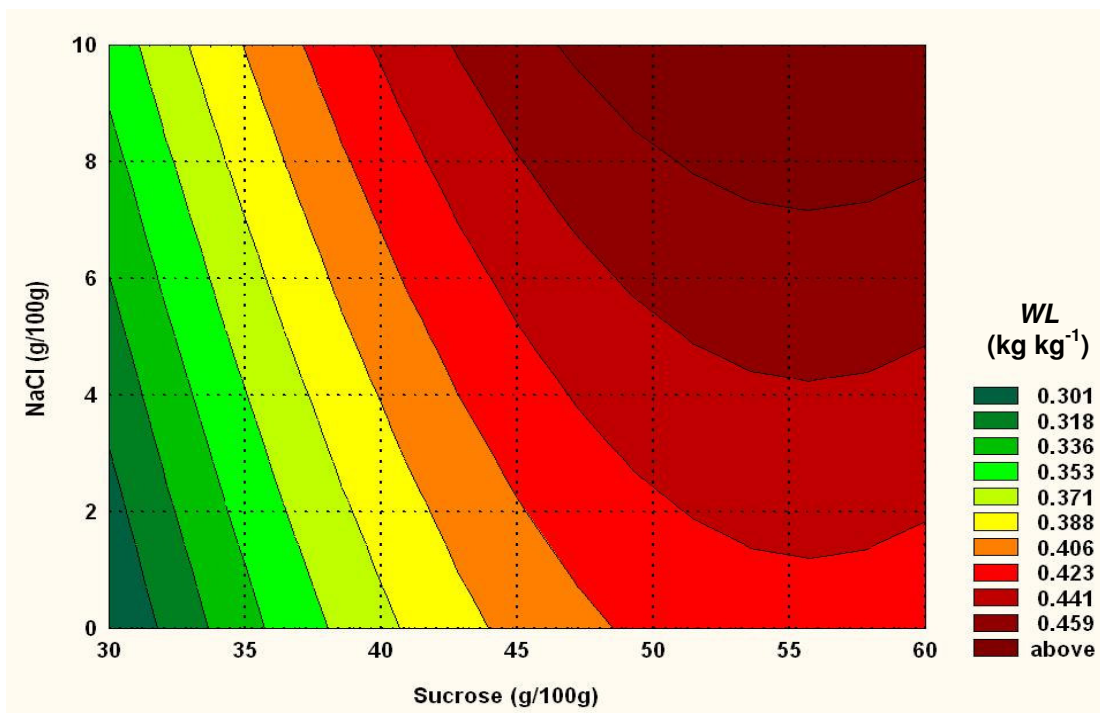
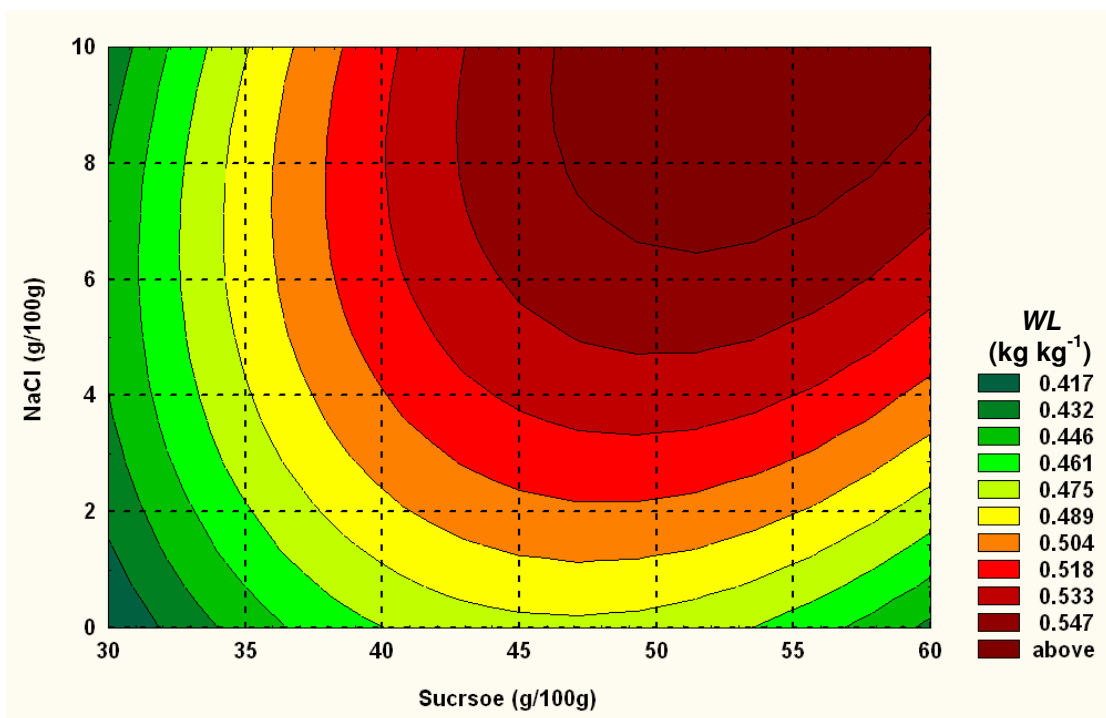
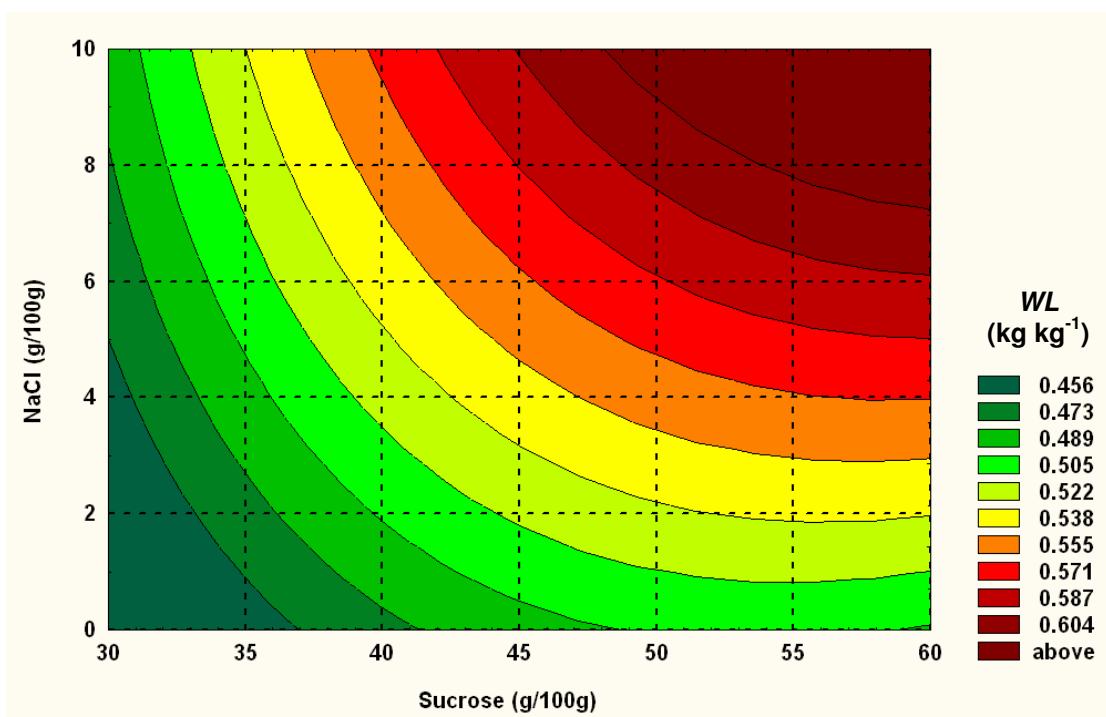


Figure 54 Response surface for *WL* as functions of sucrose and NaCl concentration (whole fruit immersed for 24 h).



**Figure 55** Response surface for  $WL$  as functions of sucrose and NaCl concentration (whole fruit immersed for 36 h).



**Figure 56** Response surface for  $WL$  as functions of sucrose and NaCl concentration (whole fruit immersed for 48 h).

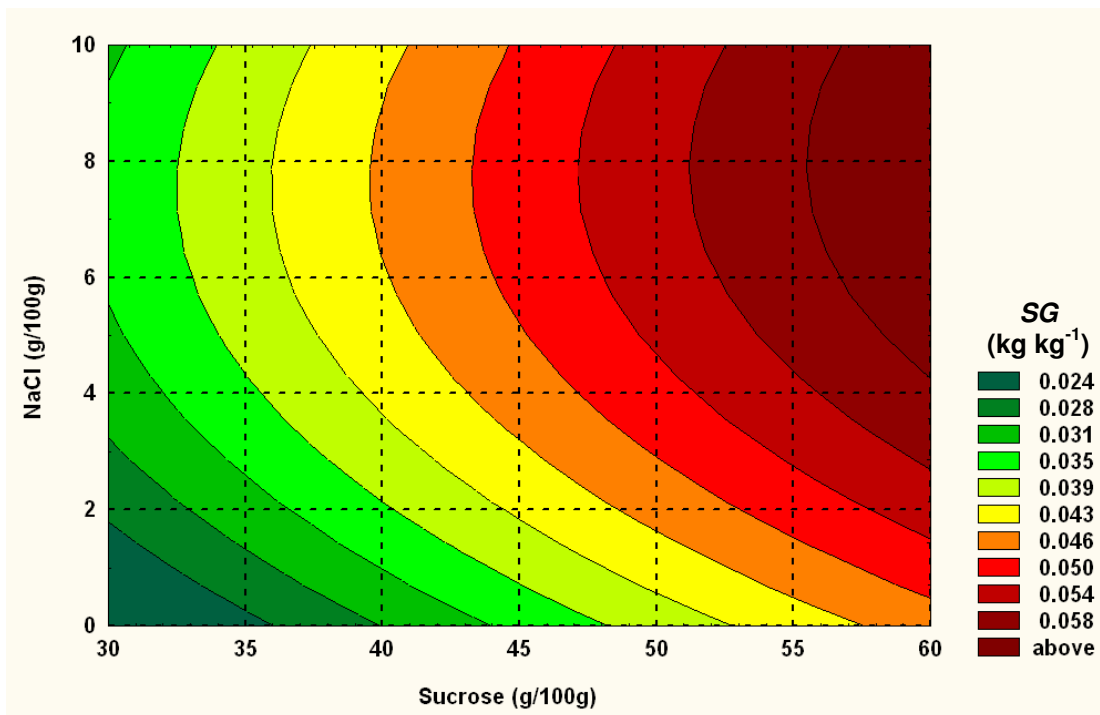


Figure 57 Response surface for *SG* as functions of sucrose and NaCl concentration (whole fruit immersed for 6 h).

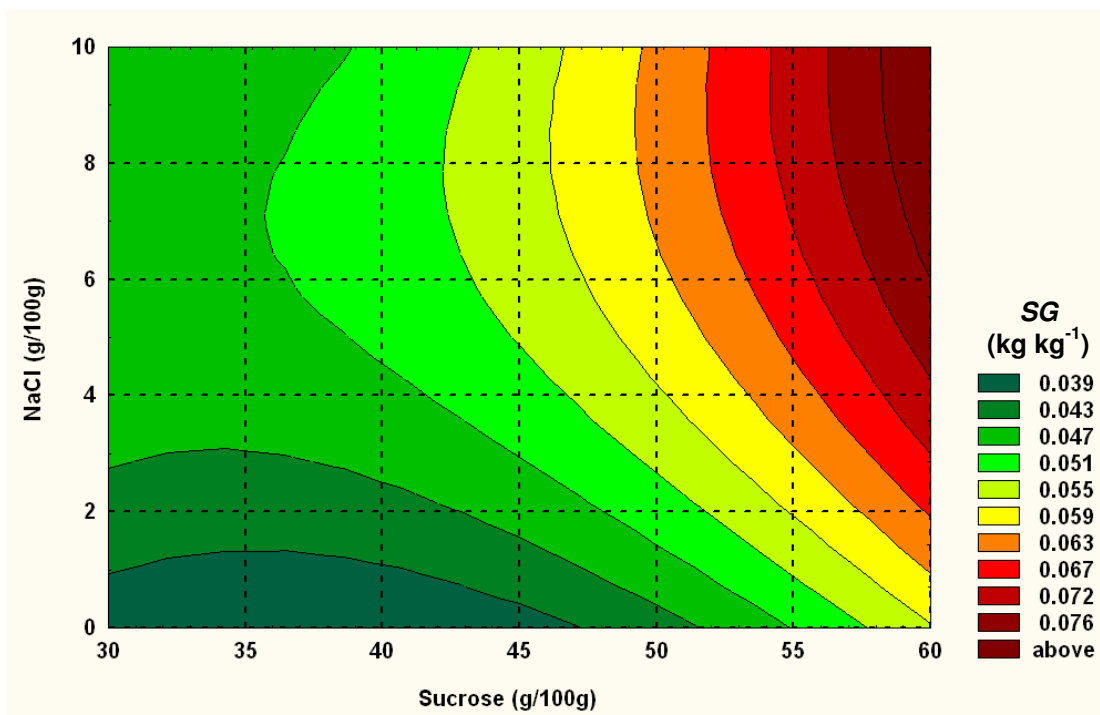


Figure 58 Response surface for *SG* as functions of sucrose and NaCl concentration (whole fruit immersed for 12 h).

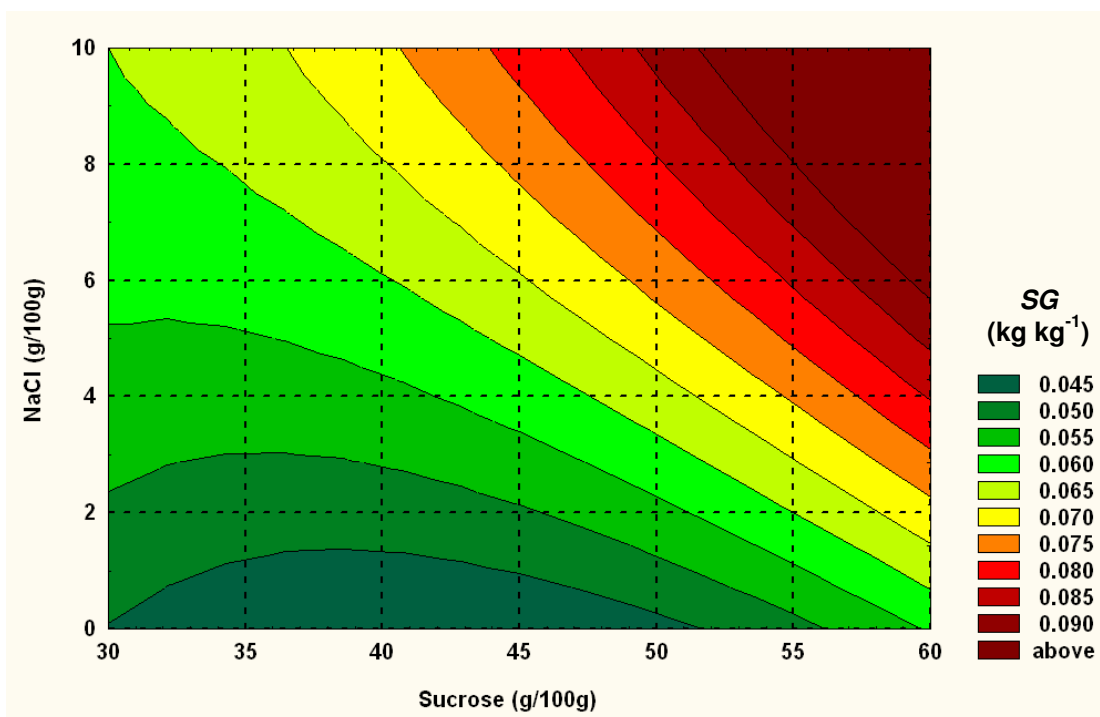


Figure 59 Response surface for *SG* as functions of sucrose and NaCl concentration (whole fruit immersed for 24 h).

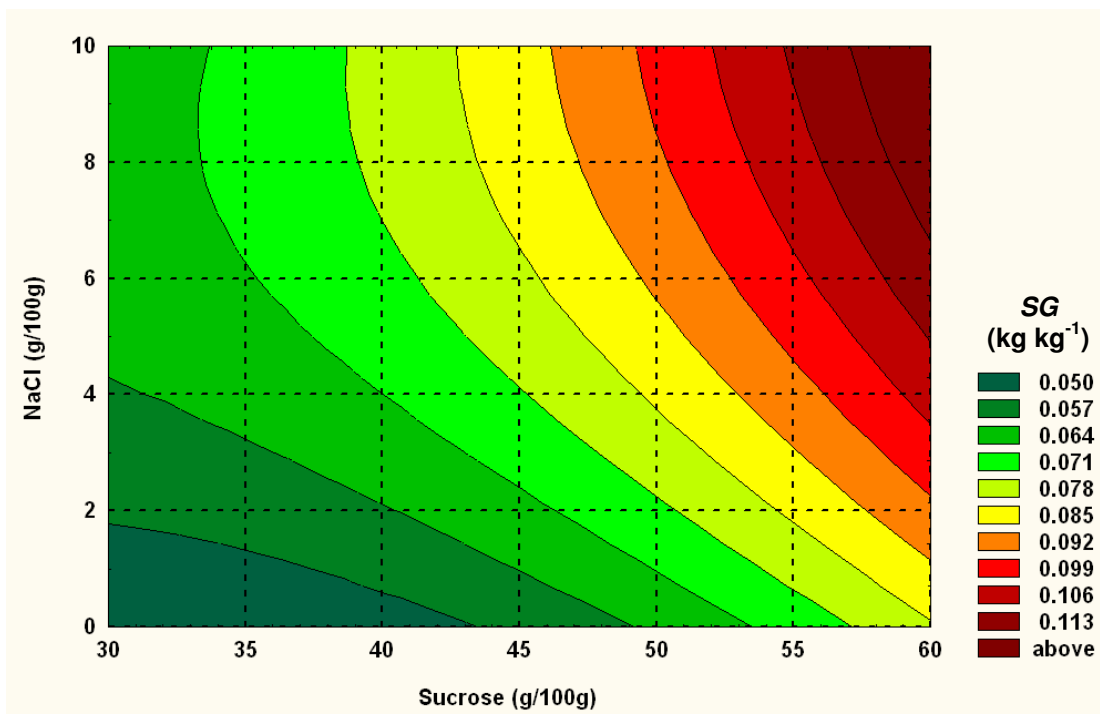
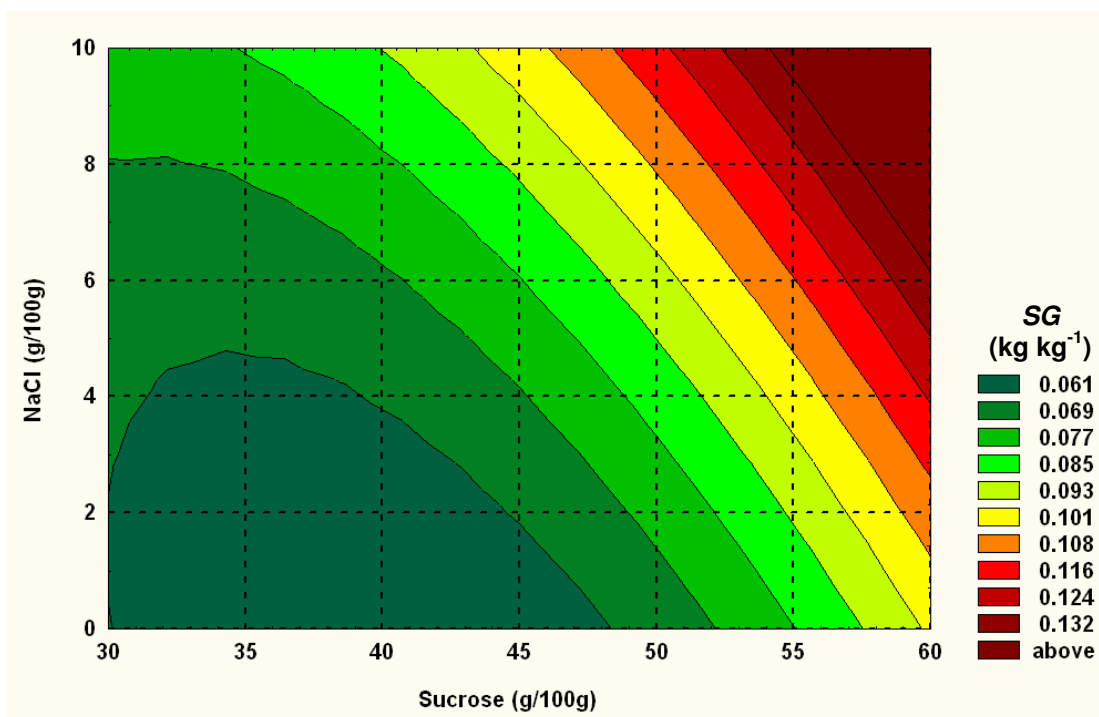
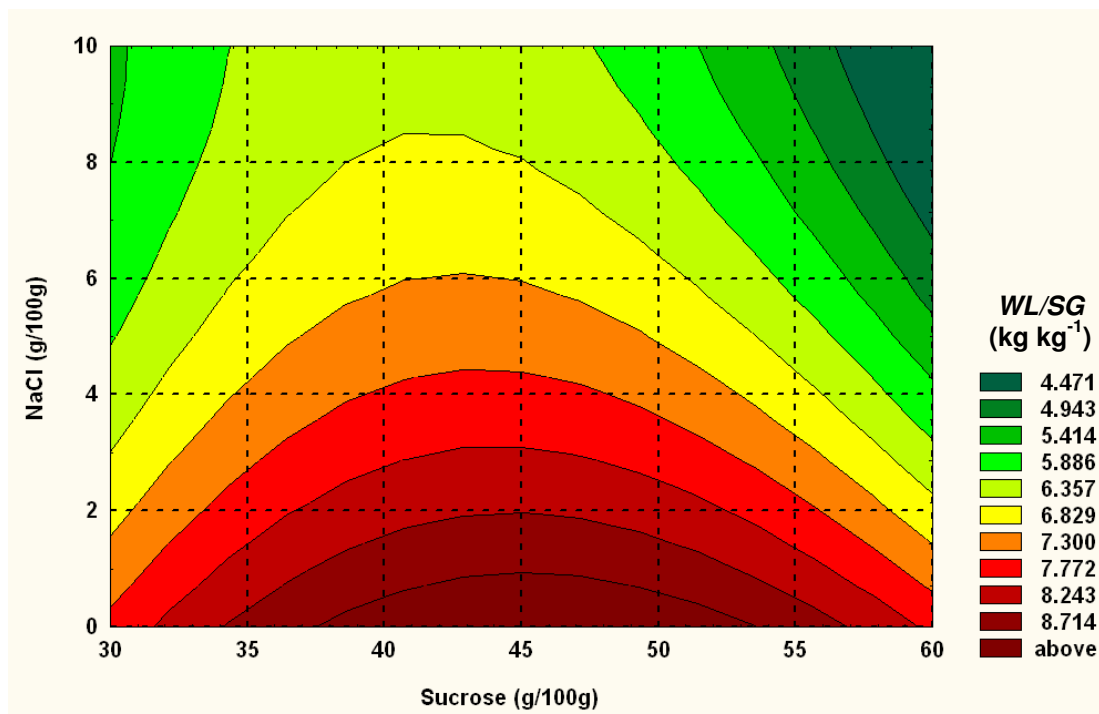


Figure 60 Response surface for *SG* as functions of sucrose and NaCl concentration (whole fruit immersed for 36 h).



**Figure 61** Response surface for  $SG$  as functions of sucrose and NaCl concentration (whole fruit immersed for 48 h).



**Figure 62** Response surface for  $WL/SG$  as functions of sucrose and NaCl concentration (whole fruit immersed for 6 h).

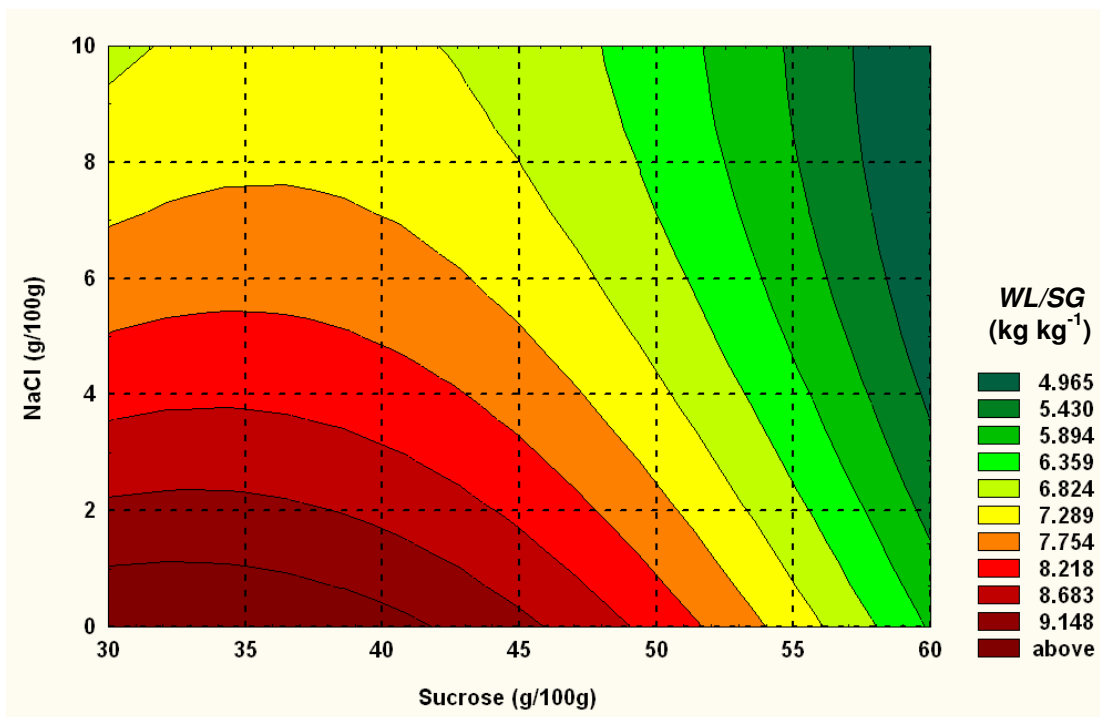


Figure 63 Response surface for *WL/SG* as functions of sucrose and NaCl concentration (whole fruit immersed for 12 h).

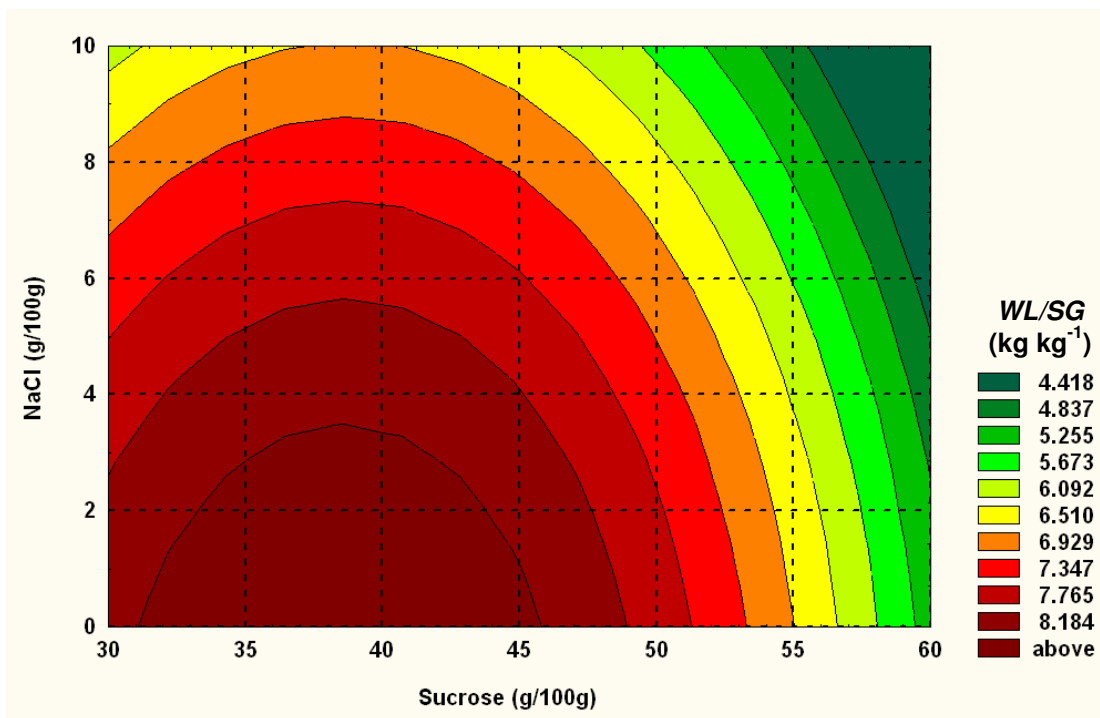


Figure 64 Response surface for *WL/SG* as functions of sucrose and NaCl concentration (whole fruit immersed for 24 h).

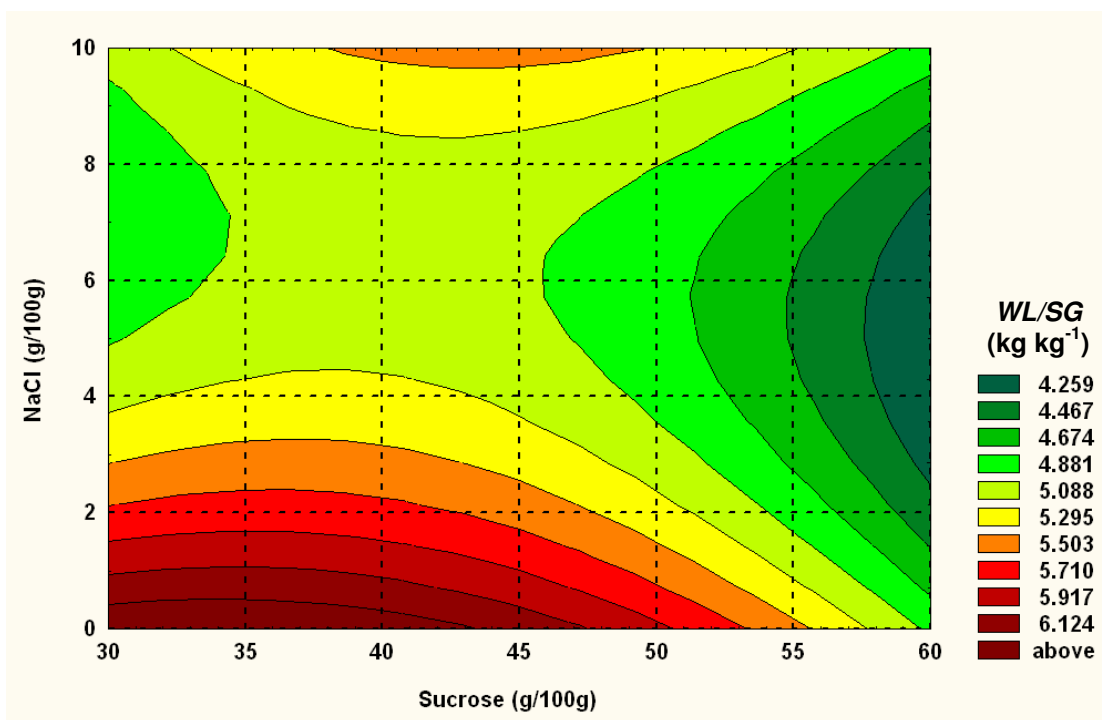


Figure 65 Response surface for *WL/SG* as functions of sucrose and NaCl concentration (whole fruit immersed for 36 h).

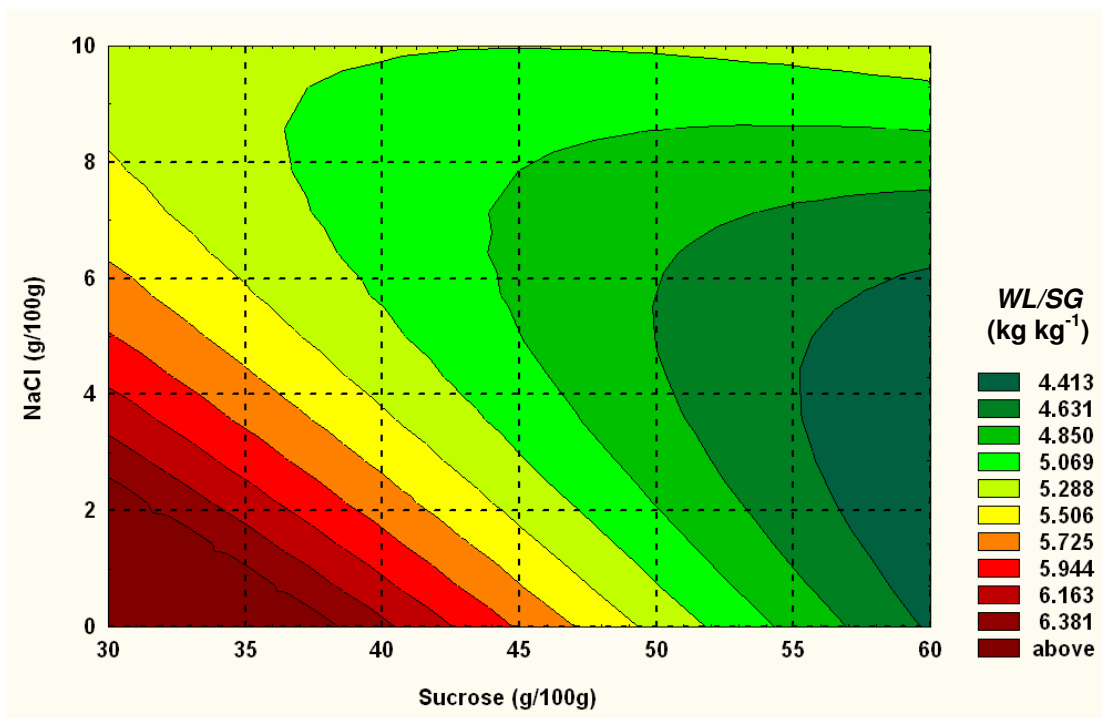


Figure 66 Response surface for *WL/SG* as functions of sucrose and NaCl concentration (whole fruit immersed for 48 h).