



Sara Hosseini

Examination of prolonged dry cold storage and hydration lengths  
during the process stage on cut roses vase life

School of Water Energy and Environment  
Agrifood

MRes

Academic Year: 2023 - 2024

Supervisors: Dr Nick Girkin, Dr MariCarmen Alamar and Dr Carol  
Verheecke-Vaessen  
March 2024



School of Water Energy and Environment

Agrifood

MRes

Academic Year 2023 - 2024

Sara Hosseini

Examination of prolonged dry cold storage and hydration lengths  
during the process stage on cut roses vase life

Supervisors: Dr Nick Girkin, Dr MariCarmen Alamar and Dr Carol  
Verheecke-Vaessen

March 2024

© Cranfield University 2024. All rights reserved. No part of this  
publication may be reproduced without the written permission of the  
copyright owner.

## **Academic integrity declaration**

I declare that:

- the thesis submitted has been written by me alone.
- the thesis submitted has not been previously submitted to this university or any other.
- that all content, including primary and/or secondary data, is true to the best of my knowledge.
- that all quotations and references have been duly acknowledged according to the requirements of academic research.

I understand that to knowingly submit work in violation of the above statement will be considered by examiners as academic misconduct.

## Abstract

Cut flowers have found an important role in human life, so market demand and cultivation are increasing. As cut flowers are highly perishable, it is important to extend their vase life to address sustainability challenges, avoid waste of natural resources, reduce carbon footprint and gain customer satisfaction.

In the UK approximately 90% of cut flowers are imported (ca. 30% represent cut roses) and kept under dry cold conditions. During periods of high consumer demand, flowers may experience prolonged dry storage time compared to the rest of the year; this can affect vase life negatively. There are few studies mimicking real supply chain scenarios and, therefore, we simulate it for cut roses in the UK to examine the impacts of prolonged dry cold storage and hydration lengths on rose vase life in two separate experiments.

The first study investigated drying lengths (24, 48, 72, and 96 hours at 5°C) on vase life of two varieties: 'Revival Sweet' and 'Golden Smile'. Interaction between drying (96 and 168 hours) and hydration solution usage time (0, 12, 24 and 48 hours) on 'Revival Sweet' was examined in the second experiment. In general, shorter drying times resulted in the longest vase life with fewer signs of physical damage (bent neck and damaged flower). In colour examination, no clear relationship between  $L^*$ ,  $C^*$  h°, drying and hydration lengths was seen which may be because of the pink colour of 'Revival Sweet'. Expanding hydration length improved solution uptake, reduced the pH, eliminated bacterial growth in vase water, preserved the sugar source and postponed senescence. When flowers were kept dry for 168 hours, hydration for 48 hours helped them show less than 50% damaged flowers and just approximately 30% bent necks after 18 days. In conclusion, during peak period, hydration for more than 24 hours is suggested to eliminate the negative impacts of prolonged dry storage.

Keywords: Preservative solutions, bent necks, bacterial count, bud diameter, petal sugar content.

## Acknowledgements

I would like to express my sincere gratitude to my supervisors, Dr Nick Girkin, Dr MariCarmen Alamar, and Dr Carol Verheecke-Vaessen, for their unwavering support throughout my thesis journey. Special thanks to Dr Sandra Landahl for her invaluable assistance with the sugar and colour data. I extend my appreciation to lab assistants Dr Emma Collings, Aleksandra Pastuszek, Monika Jodkowska, and Richard Barr for their help to the research. Thank you all for your wonderful advice and comments.

I express deep appreciation to Arena Flowers Company for their crucial sponsorship, which greatly contributed to the success of my MRes. Your support has made a lasting impact on my educational path.

A heartfelt acknowledgement goes to my friends, Julio, Marta, Fabian, and Ciara, for their camaraderie and encouragement. Thank you all for being an integral part of this academic endeavour. Finally, I am immensely grateful to my family for their unwavering support and invaluable assistance throughout my life.

## Table of contents

|                                                                                       |           |
|---------------------------------------------------------------------------------------|-----------|
| <b>Academic integrity declaration .....</b>                                           | <b>i</b>  |
| <b>Abstract.....</b>                                                                  | <b>i</b>  |
| <b>Acknowledgements .....</b>                                                         | <b>ii</b> |
| Table of contents .....                                                               | iii       |
| List of figure captions .....                                                         | vi        |
| List of table captions .....                                                          | x         |
| List of abbreviations .....                                                           | xiii      |
| <b>1 Introduction.....</b>                                                            | <b>1</b>  |
| 1.1 Aim and objectives.....                                                           | 2         |
| 1.2 Thesis structure .....                                                            | 3         |
| <b>2 Literature review: assessment of cut flower vase life .....</b>                  | <b>4</b>  |
| 2.1 Ornamental plants .....                                                           | 4         |
| 2.2 Roses .....                                                                       | 4         |
| 2.3 Life cycle assessment of cut flowers.....                                         | 5         |
| 2.4 Environmental aspects .....                                                       | 6         |
| 2.5 Packaging.....                                                                    | 7         |
| 2.6 Vase life of cut flowers.....                                                     | 7         |
| 2.6.1 Senescence.....                                                                 | 9         |
| 2.6.2 Physical damage .....                                                           | 9         |
| 2.6.3 Microbiological spoilage and postharvest diseases.....                          | 9         |
| 2.6.4 Wilting.....                                                                    | 10        |
| 2.6.5 Carbohydrates loss.....                                                         | 11        |
| 2.7 Enhancing cut-flower vase life .....                                              | 11        |
| 2.7.1 Water.....                                                                      | 12        |
| 2.7.2 Temperature .....                                                               | 12        |
| 2.7.3 Preservative solutions.....                                                     | 13        |
| 2.8 Conclusion.....                                                                   | 15        |
| <b>3 Material and methods .....</b>                                                   | <b>18</b> |
| 3.1 Plant material and sample preparation.....                                        | 18        |
| 3.2 Experimental design .....                                                         | 19        |
| 3.2.1 First experiment: effect of prolonged dry storage on two cultivars of cut roses | 19        |

|       |                                                                                                                      |    |
|-------|----------------------------------------------------------------------------------------------------------------------|----|
| 3.2.2 | Second experiment: impact of two prolonged dry storage and four hydration lengths on 'Revival Sweet' cut Roses ..... | 19 |
| 3.3   | Chemicals.....                                                                                                       | 20 |
| 3.3.1 | Chrysal RVB.....                                                                                                     | 20 |
| 3.3.2 | Flower food.....                                                                                                     | 20 |
| 3.4   | Physical measurements of flower quality .....                                                                        | 21 |
| 3.4.1 | Damaged flowers.....                                                                                                 | 21 |
| 3.4.2 | Bent neck .....                                                                                                      | 22 |
| 3.5   | Colour and bud diameter .....                                                                                        | 22 |
| 3.6   | Solution uptake.....                                                                                                 | 23 |
| 3.7   | Vase water pH and aerobic colony count.....                                                                          | 23 |
| 3.8   | Sugar content .....                                                                                                  | 24 |
| 3.9   | Statistical analysis .....                                                                                           | 25 |
| 4     | Results .....                                                                                                        | 26 |
| 4.1   | First experiment: effects of prolonged dry storage on two cultivars of cut roses<br>26                               |    |
| 4.1.1 | Bent neck .....                                                                                                      | 26 |
| 4.1.2 | Damaged flowers.....                                                                                                 | 27 |
| 4.1.3 | Solution uptake.....                                                                                                 | 28 |
| 4.1.4 | Bud diameter .....                                                                                                   | 29 |
| 4.2   | Second experiment: impacts of two prolonged dry storage and four hydration lengths on 'Revival Sweet' cut Roses..... | 31 |
| 4.2.1 | Bent neck .....                                                                                                      | 31 |
| 4.2.2 | Damaged flowers.....                                                                                                 | 32 |
| 4.2.3 | Solution uptake.....                                                                                                 | 32 |
| 4.2.4 | Bud diameter .....                                                                                                   | 33 |
| 4.2.5 | pH.....                                                                                                              | 35 |
| 4.2.6 | Aerobic colony count .....                                                                                           | 37 |
| 4.2.7 | Sugar concentration.....                                                                                             | 39 |
| 4.2.8 | Objective colour.....                                                                                                | 42 |
| 5     | General discussion and conclusion.....                                                                               | 45 |
| 5.1   | Discussion .....                                                                                                     | 45 |
| 5.1.1 | Prolonged dry storage time increases bent necks and damaged flowers during rose vase life.....                       | 45 |
| 5.1.2 | Hydration solutions can increase the resistance of flowers to physical damage 46                                     |    |
| 5.1.3 | Higher daily solution uptake demonstrates longer vase life.....                                                      | 47 |

|                  |                                                                                 |    |
|------------------|---------------------------------------------------------------------------------|----|
| 5.1.4            | Roses flower opening could be slowed down by extending the hydration time       | 49 |
| 5.1.5            | Sugar concentration impacted vase life of roses.....                            | 49 |
| 5.1.6            | Prolonged dry storage and hydration did not have considerable effects on colour | 50 |
| 5.1.7            | Challenges of the project and suggestions for improvement in future works       | 51 |
| 5.2              | Conclusion.....                                                                 | 52 |
| 5.3              | Recommendations for future experimental work .....                              | 54 |
| 5.3.1            | Investigation of the impact of individual sugar concentration on vase life      | 54 |
| 5.3.2            | Examination of packaging strategies on the vase life of cut flowers .....       | 54 |
| 5.3.3            | Determination of vase life in mixed bouquets.....                               | 54 |
| 5.3.4            | Identification of the optimal storage condition .....                           | 55 |
| 5.3.5            | Study on sustainable cut flower production and waste management .....           | 55 |
| References ..... |                                                                                 | 56 |
| Appendices.....  |                                                                                 | 67 |

## List of figure captions

**Figure 1. Life cycle stages of cut flowers** (Lan et al., 2022). Production requirements (energy, water, labour, etc.) are provided in the pre-production stage. Flowers are then grown produced (production stage) and after conservation and packaging (postharvest handling) they are transported to auctions and retail (this project focuses on this part). Customer stage, disposal and waste management come later. .... 5

**Figure 2. Examples of end of vase life in roses. a:** Signs of wilting in ‘Revival Sweet’. **b:** Signs of *Botrytis cinerea* infection on petals of ‘Revival Sweet’. **c:** advanced *Botrytis cinerea* degradation on ‘Revival Sweet’ resulted to bent neck. **d:** Signs of physical damage and bent neck on ‘Golden Smile’ and ‘Revival Sweet’ Roses (Photo by Sara Hosseini)..... 8

**Figure 3. Degradation of ‘Revival Sweet’ roses infected by *Botrytis cinerea* Pers.** Gray Mold disease can affect the petals and stems of rose buds causing significant degradation (Photo by Sara Hosseini). .... 10

**Figure 4. Taken steps during experiment one.** Flowers were kept dry at 5°C, sampling was done every 24 hours for each drying length, in each vase there was 1 litter of tap water with 1 mL Chrysal RVB holding 10 stems of roses for 24 hours. Then stems were cut at 60 cm and extra leaves and 3 external petals were removed, put in vases containing 1 litter of tap water and 5 mL Chrysal Professional 2 and moved to 18°C. . 19

**Figure 5. Taken steps during experiment two.** Flowers were kept at 5°C. After 96 and 168 hours of drying, flowers were put in 1 litre of tap water and 1 mL Chrysal RVB for 0, 12, 24, and 48 hours. After these times, stems were cut at 60 cm and extra leaves and 3 external petals were removed and put in vases containing 1 litre of tap water and 5 mL Chrysal Professional 2. After 24 hours flowers were put in vases with 1 litre of tap water with one sachet of flower food (Moonpig) and moved to 18°C..... 20

**Figure 6. Visual assessment - Comparing damaged ‘Revival Sweet’ roses with healthy ones.** Damaged roses from senescence or physical damage with more than 50% damaged petals (top) and healthy roses (down) (photo by Sara Hosseini)..... 21

**Figure 7. Comparing roses with and without bent neck.** A stem of ‘Revival Sweet’ Rose with bent neck (right) compared with a healthy one (left) (photo by Sara Hosseini). .... 22

**Figure 8. Summary of the experiments.** The first experiment examined the effects of prolonged dry storage on two cultivars of cut roses, bent necks (%), damaged flowers (%), solution uptake(mL/vase) and bud diameter (cm) were measured. The second experiment examined the impacts of two prolonged dry storage and four hydration lengths on Revival Sweet cut Roses, bent necks (%), damaged flowers (%), solution uptake(mL/vase), bud diameter (cm), colour, sugar content in petals (mg/g), vase water pH and aerobic bacterial count (CFU/mL) were done..... 25

**Figure 9. Changes in the bent necks in cut roses (%) during the vase life (day).** The percentage of bent necks was analysed in **(a):** 'Revival Sweet' and **(b):** 'Golden Smile' roses which were kept at 18°C for 20 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying length x cultivar x day has been shown where appropriate. .... 27

**Figure 10. Changes in damaged flowers (%) in cut roses during the vase life (day).** The percentage of damaged flowers was analysed in **(a):** 'Golden Smile' and **(b):** 'Revival Sweet' roses which were kept at 18°C for 20 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying x cultivar x day has been shown where appropriate. .... 28

**Figure 11. Cumulative solution uptake in cut roses (mL/vase) during the vase life (day).** The bud diameter was analysed in 'Revival Sweet' and 'Golden Smile' roses which were kept at 18°C for 20 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying x day has been shown where appropriate. .... 29

**Figure 12. Changes in bud diameter in cut roses (cm) during the vase life (day).** The bud diameter was analysed in **(a):** 'Golden Smile' and **(b):** 'Revival Sweet' roses which were kept at 18°C for 20 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying x cultivar has been shown where appropriate..... 30

**Figure 13. Changes in bud diameter in cut roses (cm) for different drying lengths on day 10 of the experiment.** The bud diameter was analysed in 'Golden Smile' and 'Revival Sweet' roses which were kept at 18°C for 20 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying length x cultivar has been shown where appropriate. .... 30

**Figure 14. Changes in the bent necks in cut roses (%) during the vase life (day).**

Flowers with bent necks were counted in each vase. Flowers with two different drying lengths (96 and 168 hours) and had 4 hydration lengths (0, 12, 24 and 48 hours) that were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions hydration length x day has been shown where appropriate..... 31

**Figure 15. Changes in damaged flowers (%) in cut roses during the vase life (day).**

Flowers with more than 50% damaged petals were counted in each vase. Flowers with two different drying lengths (96 and 168 hours) and had 4 hydration lengths (0, 12, 24 and 48 hours) that were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions hydration length x day has been shown where appropriate. .... 32

**Figure 16. Cumulative solution uptake in cut roses (mL/vase) during the vase life (day).**

Flowers with two different drying lengths (96 and 168 hours) of drying with 4 hydration lengths (0, 12, 24 and 48 hours) were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions hydration length x day has been shown where appropriate. .... 33

**Figure 17. Changes in bud diameter in cut roses (cm) during the vase life (day).**

The bud diameters were measured for flowers with two different drying lengths (96 and 168 hours) and 24 hours of hydration that were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions Drying length x day has been shown where appropriate. .... 34

**Figure 18. Bud diameter in cut roses (cm) with different drying and hydration lengths on day 18 of the vase life.**

The bud diameters were measured on the last day of the experiment for flowers with 2 drying lengths (96 and 168 hours) and 4 hydration lengths (0, 12, 24 and 48 hours) that were kept at 18°C for 18 days. Error bars represent standard deviation. .... 35

**Figure 19. Vase water pH in cut roses during the vase life (day).**

The pH of flower vase water was analysed for two different drying lengths (96 and 168 hours) which both had 24 hours of hydration length and were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying length x day has been shown where appropriate. .... 36

**Figure 20. Vase water pH in cut roses with different hydration lengths on day 18 of the vase life.** The pH of flower vase water was analysed for two different drying lengths (96 and 168 hours) which had 0, 12, 24 and 48 hours of hydration and were kept at 18°C for 18 days. Error bars represent the standard deviation..... 37

**Figure 21. Total aerobic colonies plate count in vase water of cut roses during the vase life (day).** The aerobic colonies were counted in the vase water of flowers with two different drying lengths (96 and 168 hours) which both had 24 hours of hydration length and were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying length x day has been shown where appropriate..... 38

**Figure 22. Total aerobic count in vase water of cut roses on the final day of the experiment.** On day 18, the aerobic colony count was evaluated in the vase water of flowers with two different drying lengths (96 and 168 hours) which had different hydration lengths (0, 12, 24 and 48 hours) and were kept at 18°C for 18 days. Error bars represent the standard deviation. Least significant difference (LSD) ( $p < 0.05$ ) bars for the interactions drying length x hydration length have been shown where appropriate. .... 39

**Figure 23. changes in individual sugar (glucose, fructose, and sucrose) concentration during the vase life (day).** The concentration of individual sugar were measured in the petals of flowers with two different drying lengths (96 and 168 hours), both of which underwent 24 hours of hydration and were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the day has been shown where appropriate. .... 40

**Figure 24. Individual sugar concentration on day 18 of the vase life.** On day 18, the concentration of sugars (a: sucrose, b: fructose and c: glucose) was measured in the petals of flowers with two different drying lengths (96 and 168 hours) which had different hydration lengths (0, 12, 24 and 48 hours) and were kept at 18°C for 18 days. Error bars represent the standard deviation. The interaction between drying time and hydration time was not significant, hence.  $LSD_{0.05}$  is not shown. .... 41

**Figure 25. Chroma (C\*) and lightness (L\*) of roses' petals during the vase life (day).** a: chroma (C\*) and b: lightness (L\*) were measured in the petals of flowers with two different drying lengths (96 and 168 hours) which both had 24 hours of hydration length and were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for interactions drying length x day has been shown where appropriate..... 43

**Figure 26. Lightness (L\*) and hue angle (h°) of roses' petals on the final day of the experiment.** a: hue angle (h°) and b: chroma (C\*) were measured in the petals of flowers with two different drying lengths (96 and 168 hours) which had different hydration lengths (0, 12, 24 and 48 hours) and were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bars for the interactions drying length x hydration length have been shown where appropriate..... 44

**Figure 27. Stem damage on 'Revival Sweet' Roses.** Stem rottenness (red box) caused by *Botrytis cinerea* Pers had stopped solution uptake and led to wilting and bent necks (yellow box) (photo by Sara Hosseini). A close zoom of *Botrytis cinerea* Pers infection is shown on the right. .... 48

**Figure 28. Example of a picture that was difficult to obtain RGB in.** Because there are three buds with bent necks it was impossible to see the whole cross-section of the buds. In addition, the brown colour resulting from *Botrytis cinerea* can affect the results negatively (photo by Sara Hosseini)..... 52

## List of table captions

**Table 1. Flowers area, value of production and trades in the UK** between 2020 and 2022 (United Kingdom Government, 2022)..... 2

**Table 2. Examples of optimal temperature demands for different flowers.** Each flower shows the longest longevity when they are stored at the mentioned temperatures (Gupta & Dubey, 2018). .... 12

**Table 3. The effective factors on cut flower vase life.** Different papers have been summarized to compare and organise all factors in the same place. .... 16

**Table 4. ANOVA table for bent necks during the time.** Results of bent necks (%) for 'Golden Smile' and 'Revival Sweet' roses at different drying lengths and days were analysed with general ANOVA. .... 67

**Table 5. ANOVA table for damaged flowers.** Results of damaged flowers (%) for 'Golden Smile' and 'Revival Sweet' roses at different drying lengths and days were analysed with general ANOVA. .... 67

|                                                                                                                                                                                                                                                            |    |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| <b>Table 6. ANOVA table for solution uptake.</b> Results of solution uptake (mL/vase) for ‘Golden Smile’ and ‘Revival Sweet’ roses at different drying lengths and days were analysed with general ANOVA. ....                                             | 67 |
| <b>Table 7. ANOVA Table for Bud diameter.</b> Results of bud diameter (cm) for ‘Golden Smile’ and ‘Revival Sweet’ roses at different drying lengths and days were analysed with general ANOVA. ....                                                        | 68 |
| <b>Table 8. ANOVA table for bent necks.</b> Results of bent necks (%) for ‘Revival Sweet’ roses at different drying and hydration lengths and days were analysed with general ANOVA. ....                                                                  | 68 |
| <b>Table 9. ANOVA table for damaged flowers.</b> Results of damaged flowers (%) for ‘Revival Sweet’ roses at different drying and hydration lengths and days were analysed with general ANOVA. ....                                                        | 68 |
| <b>Table 10. ANOVA table for solution uptake.</b> Results of solution uptake (mL/vase) for ‘Revival Sweet’ roses at different drying and hydration lengths and days were analysed with general ANOVA. ....                                                 | 69 |
| <b>Table 11. ANOVA table for bud diameter during time.</b> Results of bud diameter (cm) for ‘Revival Sweet’ roses at different drying lengths (96 and 168 hours) and 24 hours of hydration during time were analysed with two-way ANOVA. ....              | 69 |
| <b>Table 12. ANOVA table for bud diameter on day 18.</b> Results of bud diameter (cm) for ‘Revival Sweet’ roses at different drying (96 and 168 hours) and hydration (0, 12, 24 and 48 hours) lengths on day 18 were analysed with two-way ANOVA. ....     | 69 |
| <b>Table 13. ANOVA table for vase water pH during time.</b> Results of vase water pH for ‘Revival Sweet’ roses at different drying lengths (96 and 168 hours) and 24 hours of hydration during time were analysed with two-way ANOVA. ....                 | 69 |
| <b>Table 14. ANOVA table for roses vase water pH on day 18.</b> Results of vase water pH for ‘Revival Sweet’ roses at different drying (96 and 168 hours) and hydration (0, 12, 24, and 48 hours) lengths on day 18 were analysed with two-way ANOVA. .... | 70 |
| <b>Table 15. ANOVA table for aerobic colony count in vase water during time.</b> Results of aerobic colony plate count for ‘Revival Sweet’ roses at different drying lengths (96 and                                                                       |    |

168 hours) and 24 hours of hydration during time were analysed with two-way ANOVA.  
 ..... 70

**Table 16. ANOVA table for aerobic colony count in vase water on day 18.** Results vase water aerobic colony count for ‘Revival Sweet’ roses at different drying (96 and 168 hours) and hydration (0, 12, 24, and 48 hours) lengths on day 18 were analysed with two-way ANOVA. .... 70

**Table 17. ANOVA table for individual sugars.** individual sugars (a: sucrose, b: fructose and c: glucose) in petals of flowers with the 24 hours hydration length and different drying lengths (96 and 168 hours) and days. .... 70

**Table 18. ANOVA table for individual sugars.** Individual sugars (a: sucrose, b: fructose and c: glucose) in petals of flowers with different drying (96 and 168 hours) and hydration (0, 12, 24 and 48 hours) lengths were measured on day 18. .... 71

**Table 19. ANOVA table for objective colour during vase life.** Objective colour (a: Chroma ( $C^*$ ), b: Lightness ( $L^*$ ) and c: Hue angle ( $h^\circ$ )) in petals of flowers with 24 hours hydration length, different drying lengths (96 and 168 hours) and days were measured.  
 ..... 71

**Table 20. ANOVA table for objective colour on day 18.** Objective colour (a: Chroma ( $C^*$ ), b: Lightness ( $L^*$ ) and c: Hue angle ( $h^\circ$ )) in petals of flowers with different drying and hydration lengths were measured on day 18. .... 72

## List of abbreviations

|                     |                                        |
|---------------------|----------------------------------------|
| %                   | percent                                |
| £                   | pounds                                 |
| <                   | less than                              |
| °C                  | degree Celsius                         |
| µL                  | microliter                             |
| AgNO <sub>3</sub>   | Silver nitrate                         |
| Al(OH) <sub>3</sub> | Aluminium hydroxide                    |
| ANOVA               | Analysis of variance                   |
| C*                  | Chroma                                 |
| ca.                 | circa                                  |
| CFU                 | Colony formation unit                  |
| cm                  | centimetre                             |
| CO <sub>2</sub>     | carbon dioxide                         |
| DW                  | dry weight                             |
| EU                  | European Union                         |
| h°                  | Hue angle                              |
| ha                  | hectare                                |
| i.e.                | for example                            |
| L                   | litre                                  |
| L*                  | Lightness                              |
| LDPE                | low-density polyethene                 |
| Mg                  | milligram                              |
| mL                  | millilitre                             |
| O <sub>2</sub>      | oxygen                                 |
| Po                  | Polyolefin                             |
| PP                  | polypropylene                          |
| TDS                 | Total Dissolved Solids                 |
| UK                  | United Kingdom                         |
| VT                  | variable temperature                   |
| w/v                 | weight/volume percentage concentration |

## 1 Introduction

The ornamental plant industry, particularly cut flowers, has seen a surge in interest over the last century, with ornamental plants playing an important role in various events and occasions (Zhuang et al., 2021) from weddings to funerals. There are several reasons for this development, including an increase in online sales channels that have provided the availability of different types of flowers for everyone.

Flower production or floriculture is a highly developed and specialized form of agriculture (Manikas et al., 2020). Quality evaluation in the cut flower industry has usually been dependent on the cut flowers' appearance, which includes their size, colour, and shape in addition to the stem length and form (Reid, 2016). One of the most significant factors in consumers' purchase decisions about cut flowers is their internal quality or longevity, as their short and erratic nature leads to low customer satisfaction (Rihn et al., 2014). Longevity of cut flowers is defined as vase life which is the duration for which cut flowers remain viable and aesthetically pleasing after being harvested and placed in a vase or other container (Shewfelt & Prussia, 2021).

In the United Kingdom (UK) alone, ornamental plants and flowers valued at £1.5 billion in 2022. with most of them (90%) being imported, as the Netherlands, Kenya and Colombia are the main countries in terms of imports (Statista, 2022). Moreover in 2022, 165,000 ha of land were cultivated for flowers for UK markets, with a total value of £26 million (Table 1), (United Kingdom Government, 2022). Notably, the cut flower industry faces a challenge in maintaining customer satisfaction due to the vulnerability of cut flowers to damage and their varying longevity depending on species (Mochizuki et al., 2019), variety (Klatt et al., 2013), the application of storage solutions, flower preparation and storage conditions (Sun et al., 2022).

**Table 1. Flowers area, value of production and trades in the UK** between 2020 and 2022 (United Kingdom Government, 2022).

|                         | 2020   | 2021   | 2022   |
|-------------------------|--------|--------|--------|
| Area (ha)               | 127000 | 129000 | 165000 |
| Trade (£million)        | 643    | 693    | 705    |
| Total export (£million) | 26     | 22     | 23     |

Because doorstep delivery is becoming more and more popular and e-commerce is becoming widely used, online sales channels have become a very promising market. Due to this trend, several online flower delivery businesses have emerged to meet the demands of customers looking for unique and customized floral arrangements. 'Arena Flowers', a gifts and flower retailer based in the UK, sponsored this research project with the purpose of overcoming current challenges associated with high spoilage and waste due to non-optimised storage conditions with cut flowers they are facing and suggest solutions to expand cut flower longevity.

### 1.1 Aim and objectives

This study aims to expand the number of days that cut roses stay in an acceptable state (having more than 40% freshness) before the end of their consumer use, by quantifying the physiological changes in quality parameters and identifying potential interventions to enhance quality through time. This project seeks to address the following research questions:

1. What are the impacts of prolonged drying on cut flower vase life?
2. What are the simultaneous impacts of different prolonged drying and hydration lengths on cut flower vase life?

Hypotheses:

1. Longer dry storage time would lead to a shorter vase life.
2. Expanding hydration time may improve flower vase life in prolonged dry storage conditions.

## **1.2 Thesis structure**

In the first part, a brief introduction is provided followed by aims and objectives. After that, a review of previously conducted research is introduced to find out the current progress in the cut flower vase life. The next section presents the materials and methods used to carry out the research work. Then, the results of both experiments are provided: the first experiment looked at the effects of prolonged dry periods on two different cultivars of cut roses ('Golden Smile' and 'Revival Sweet'), whilst the second experiment investigated the interaction between different drying and hydration lengths on 'Revival Sweet' cut roses. The final section presents general discussion, conclusion, and future perspectives.

## 2 Literature review: assessment of cut flower vase life

### 2.1 Ornamental plants

The main reason ornamental plants are grown is for their beauty, and they are an important part of the agricultural industry (Doublet et al., 2022). Cut flowers are considered one of the most used ornamental plants. Among them, roses (*Rosa hybrida* L.) are the most popular and commercially available cut flower as about 30% of the world's global ornamental market accounts for them (Kenanoğlu, 2023). They are gifted in a variety of events and occasions (Li et al., 2016) such as birthdays, weddings, graduations, etc. With an increasing growth population, the advancement of civilizations, and the proliferation of numerous events and occasions, cut flowers have found an undeniable part in people's lives (Altman et al., 2022).

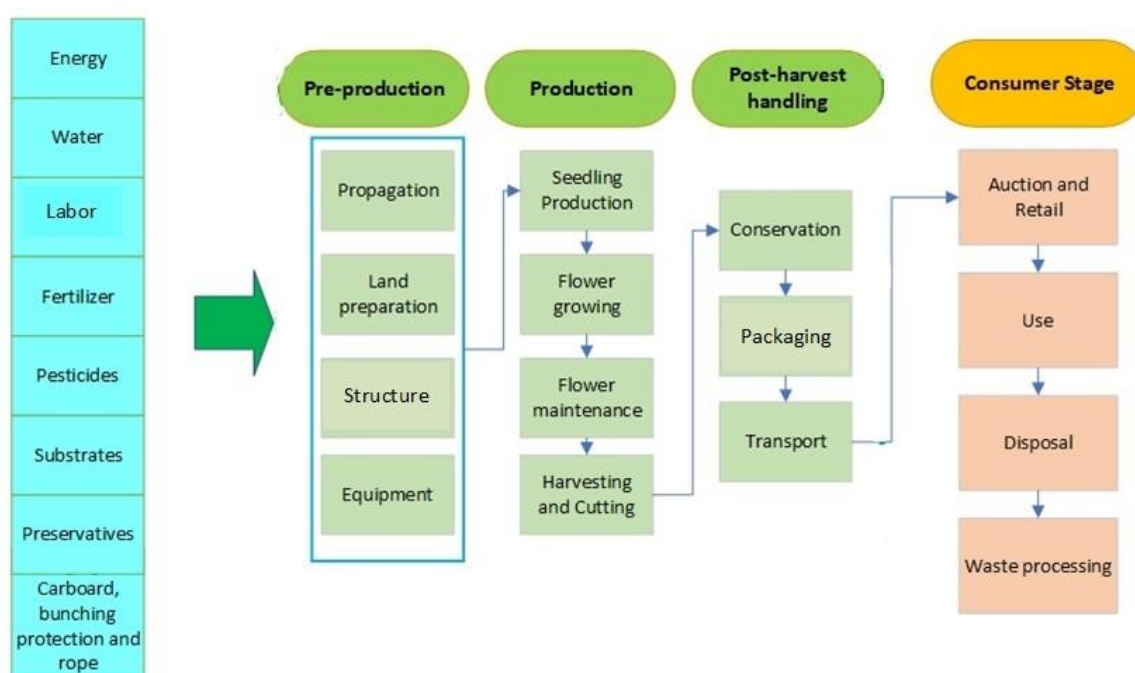
### 2.2 Roses

Among cut flowers, the rose ranks first over all other flowers in the ornamental plants market (Kenanoğlu, 2023). They are valued for their delicate nature, beauty, charm, and in certain instances their fragrances and are widely utilised for ornamental purposes. They are iconic flowers and have been also garden flowers. The rose symbolises excellence, elegance, romance, and love since the beginning of civilisation. Greek poetess first referred to the rose as "The Queen of Flowers" in her "Ode to the Rose". They are members of the *Rosaceae* family, which includes more than 150 species and 1400 cultivars (Vukosavljev et al., 2013).

The main aim of rose plant cultivation is to yield cut flowers, which significantly affects the floricultural industry (Khan et al., 2015). They are employed in the agriculture-based business, particularly in cosmetics and perfumes, and are known for their great economic value. This is a fact that cut roses unlike entire flowers, which go through the entire natural senescence process, frequently end their vase life at an early stage of maturity because of petal withering and abscission or bent neck (Burdett, 2022; Loubaud & Van Doorn, 2004; Staby & Erwin, 2022). Cut rose vase life is 4-14 days and it varies not only between cultivars but also between seasons, it mostly depends on the genetic characteristics of the various varieties and environmental conditions (Ichimura & Goto, 2002; Mortensen & Gislerød, 1999).

## 2.3 Life cycle assessment of cut flowers

There are four main stages in the supply chain of the cut flower industry: preproduction, production, postharvest processing, and consumer stage (Figure 1) (Lan et al., 2022). Cut flower production starts with cultivating fresh flowers for consumption and ends with waste processing (Lan et al., 2022). The cultivation process and flower requirements, from cultivation to harvest, depend on their species, and producers are responsible for meeting those demands to produce quality flowers. The final stage, customer stage, largely depends on the customers' behaviour (Sahle & Potting, 2013; Soode et al., 2015).



**Figure 1. Life cycle stages of cut flowers** (Lan et al., 2022). Production requirements (energy, water, labour, etc.) are provided in the pre-production stage. Flowers are then grown produced (production stage) and after conservation and packaging (postharvest handling) they are transported to auctions and retail (this project focuses on this part). Customer stage, disposal and waste management come later.

If the grower wants to maximize value, flowers should have a maximum shelf life or vase life, be free of insect or disease infestation, and be free of any physiological or physical injuries. To satisfy these demands, the modern global flower production industry has been evolving over the years with the popularity of cold chain (Babalola et al., 2011) and preservative solutions (Khan et al., 2015). This project focuses on the processing stage of cut roses (postharvest handling, auction, retail, and use) which

includes actions that must be taken by businesses involved in the cut flower supply chain.

## **2.4 Environmental aspects**

In many areas of agriculture, we have been aware of the unintended impacts of our activities on the environment, and floriculture production is not an exception. These impacts can be related to production, sale path or waste management (Leon et al., 2023).

Compared to other crops like tomatoes, lettuce, and rice, cut flowers require higher levels of pesticide application (Etheredge & Waliczek, 2022). The production of the floriculture sector is largely concentrated in developing countries, where there may be fewer environmental laws on pesticides that are otherwise banned or restricted in other countries, as a result, there is a higher chance of pesticide exposure there (Damalas & Eleftherohorinos, 2011). Consequently, because of the possibility of excessive pesticide leaking into land and waterways, additional attention should be given to cutting flower disposal from floral shops, which is a great topic for future research.

Consumer expectations and desire to purchase flowers have been improved. Some consumers decide to purchase cut flowers according to their emotions which are related to authenticity, environmental friendliness, sustainability, or ecological purity. For instance, it is important if recyclable materials are used for flower design and packaging (Harford, 2019). Based on this background, flower growers are increasingly aware promotion of the ecological friendliness of flowers can influence purchase decisions. As a result, several sustainability-focused certificates and labels are present for cut flowers, indicating that their products have met specific criteria regarding reduced fertilizer and pesticide usage, absence of toxicity, and adherence to fair labor practices, among other factors (Mengistie et al., 2017).

Considering the necessity of proper marketing and supply of manufactured products in global markets, the quality and vase life of flowers after harvesting are important factors that are effective in the formation of new and appropriate methods of packing and storing flowers (Macnish et al., 2009). Generally, to achieve maximum benefits and the lowest negative impacts on the environment growers must use environmentally friendly packaging materials with the proper way of storing flowers after harvesting.

## 2.5 Packaging

Cut flowers are a highly perishable product that is susceptible to a variety of postharvest losses. Around 20 to 40% of the market for cut flowers is lost because of ineffective postharvest handling and packaging (Fatima et al., 2022). A crucial component of postharvest management for highly perishable commodities is packaging. Appropriate packaging during transportation is essential and it can reduce physical damage and maintain flowers' aesthetic longevity (Jawaharlal et al., 2012).

Flower quality maintenance, water loss minimization, against physical harm, ease of use, traceability, and making the floral product easy to handle in transportation are required characteristics of packaging material. Strong enough, resistant to moisture, affordable or reusable, and compatible with packing line equipment are some of the attributes of packaging material (Bradley & Corsini, 2023). For the best passive modification of CO<sub>2</sub> and O<sub>2</sub> levels during storage, choosing the right packaging material is important (Wilczyńska et al., 2023).

There are many different packaging materials used for packaging flower spikes, however, the most common ones include polypropylene (PP), low-density polyethylene (LDPE), polyolefin (PO), cellophane, butter paper, newspaper protection, and banana leaves (Thakur, 2020). Kumar et al. (2019), examined the effects of PO, newspaper, butter paper, LDPE, and aluminium foil to wrap flowers under different temperatures on the physical characteristics and vase life of rose and plumeria flowers. PO-packed flowers maintained in a refrigerator showed the least amount of size decrease; the reason for this is that flowers wrapped in PO lost a small amount of water when they were stored. Flowers packed in aluminium foil and kept at room temperature showed the largest bud size reduction, which means they lost a higher amount of water (Kumar et al., 2019).

## 2.6 Vase life of cut flowers

The term "vase life" describes how long cut flowers stay attractive and viable after being harvested and placed in a vase or other container (Shewfelt & Prussia, 2021). Cut flowers may be rejected from the market if the quality of the stems, leaves, or buds is lost. Some of them may experience quality loss because of one or more of the following conditions: withering or abscission of leaves and/or petals; leaf yellowing;

and geotropic or phototropic bending of buds and stems (Ahsan et al., 2021). The end of vase life can be in different forms, wilting of the stem or bud resulting in bent necks, loss of colour brightness, loss of a key aesthetic feature like petals, and finding signs of physical damage or wilting in more than 50% of the pedals (Figure 2). Before examining factors that affect the life of cut flowers and how to maximize their longevity, understanding the sources of quality degradation is important.



**Figure 2. Examples of end of vase life in roses.** **a:** Signs of wilting in ‘Revival Sweet’. **b:** Signs of *Botrytis cinerea* infection on petals of ‘Revival Sweet’. **c:** advanced *Botrytis cinerea* degradation on ‘Revival Sweet’ resulted to bent neck. **d:** Signs of physical damage and bent neck on ‘Golden Smile’ and ‘Revival Sweet’ Roses (Photo by Sara Hosseini).

According to Maree & van Wyk (2020) cut flowers' vase life in room temperature varies between 5 to 14 days on average. It is influenced by some factors, including the species or cultivar (Wu et al., 1991), temperature and environmental conditions (Vesprini & Pacini, 2005), water availability and uptake (Jorgensen & Arathi, 2013), and the presence of microorganisms (Zagory & Reid, 2022).

Short flower vase life can be due to multiple parameters including depletion of organic reserve compounds through respiration (da Costa & Finger, 2016), contamination with fungi or bacteria (Muñoz et al., 2019), physical damage (Jia et al., 2021), wilting (Elhindi, 2012), quality of water (Costa et al., 2015; Van Doorn, 2012), storage temperature (Menegaes et al., 2019), and rise on the sensitivity of ethylene (Khunmuang et al., 2019).

### 2.6.1 Senescence

The final stage of a flower's development, known as flower senescence. It is a sophisticated metabolic process that is tightly regulated by the environment and heredity (Rabiza-Świder et al., 2016). Senescence ultimately leads to death of some organs or whole plants and includes wilting, part shedding and blossom fading (Tripathi & Tuteja, 2007).

The senescence event shares characteristics of programmed cell death, such as modifications to chemistry, metabolism, and vascular structure (Van Doorn & Woltering, 2004). Senescence is a highly controlled process that includes the production of various hydrolases that hydrolyse polymers like carbohydrates, proteins, lipids, and nucleic acids, as well as the progressive closure of several biosynthetic pathways (Tripathi & Tuteja, 2007). After hydrolysing, the products are transferred to tissues that are just beginning to grow. Plant senescence is hence an essential step that helps plants save energy and materials (Rogers, 2006). Therefore it is possible to extend cut flower vase life by postponing senescence.

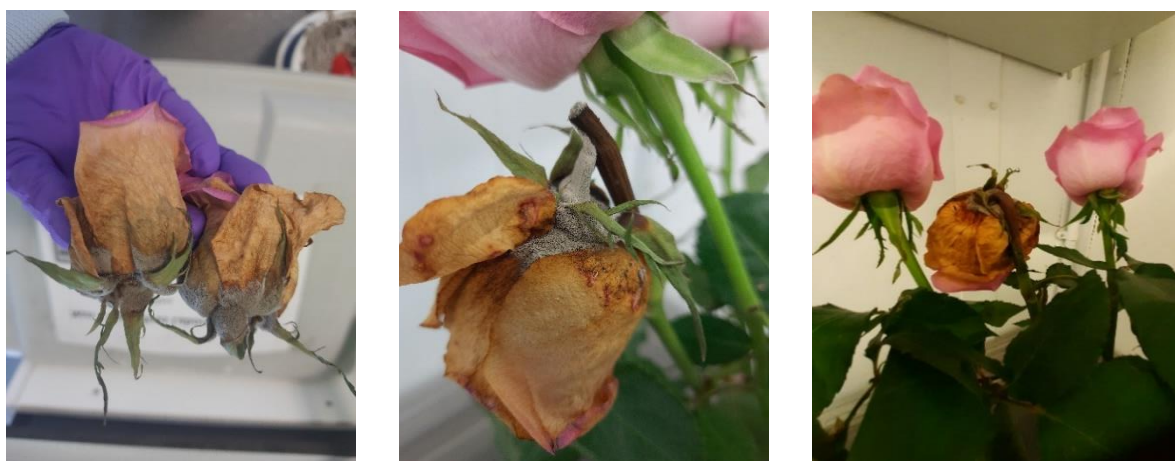
### 2.6.2 Physical damage

Improper handling during harvesting, sorting, storage, and transportation causes physical damage, leads to increases in respiration rate and reduces flower vase life (Gómez-Merino et al., 2020). Another factor that may lead to physical damage and limited vase life is exposure to unsuitable temperatures for a long time (Çelikel et al., 2020), as high temperature leads to a heat shock (Seaton & Joyce, 1993) and too low temperature leads to chilling injury (Darras, 2020). According to Çelikel & Reid (2002), temperature leads to chilling injury (Darras, 2020). According to Çelikel & Reid (2002), the respiration rate of cut gerbera (*Gerbera jamesonii* H. Bolus ex Hook.f. *Vesuvio*) and sunflower (*Helianthus annuus* L.) increase exponentially with increasing storage temperature, resulting in flowers having a shorter vase life. Higher storage temperature leads to more physical damage and bent neck (Burdett, 2022).

### 2.6.3 Microbiological spoilage and postharvest diseases

Ha et al. (2021) identified fungi including *Botrytis cinerea*, *Cladosporium macrocarpum* preuss, *Fusarium oxysporum*, and *Rhizopus stolonifera*, as well as bacteria like *Pseudomonas fluorescens*, *Enterobacter cloacae*, and *Salmonella typhimurium*, as key drivers in the deterioration of cut rose flowers.

Postharvest diseases mostly happen due to pathogenic infections. High humidity in packages over transportation shortens the postharvest life of the flowers, it can cause bacterial and fungal diseases (Öztürk & Bastas, 2022). *Magnaporthe oryzae* is one of the fungal pathogens for cut flowers, which is also the most devastating rice pathogen in the world (Ou, 1980). *Botrytis cinerea* and *Cladosporium macrocarpum preuss* are the common pathogens of fungal disease with a necrotrophic nutritional mechanism that can destroy cut flowers (Kaur et al., 2023). In greenhouses, open fields, and during storage, including cold storage (0–10°C), Gray Mold is a common fungal disease caused by *Botrytis cinerea* that is thought to be the second most important phytopathogen responsible for pre- and postharvest decay in flowers (Dean et al., 2012) (Figure 3).



**Figure 3. Degradation of 'Revival Sweet' roses infected by *Botrytis cinerea* Pers.** Gray Mold disease can affect the petals and stems of rose buds causing significant degradation (Photo by Sara Hosseini).

#### **2.6.4 Wilting**

Most cut flowers' vase life usually ends when they start to show signs of wilting (Halevy & Mayak, 2011) which mostly happens due to senescence-related natural water loss combined with increased respiration, and potential bacterial or fungal blockage of the xylem (Sun et al., 2001). Xylem blockage can be caused due to water deficit (Nijssen et al., 2000), air or high concentrations of bacteria in the vase water (van Doorn et al., 1991) and physiological stem clog (Vaslier & Van Doorn, 2003), demonstrating that water uptake is important, particularly, when it comes to the later stages of the vase life. The quality of water and the presence of contaminations, such as fungi or bacteria, or the high content of salts, especially chlorine, reduce flower longevity (Costa et al., 2015). According to Elgimabi (2011), 30 mg/l silver nitrate ( $\text{AgNO}_3$ ) combined with 3% (w/v)

sucrose resulted in the longer vase life of cut roses (*Rosa hybrida*) by 10 days and this also decreased the percentage of wilting by 10%.

### **2.6.5 Carbohydrates loss**

It is proven that the progressive reduction in carbohydrate levels during senescence plays a pivotal role in the wilting and aging process of roses, this emphasizes the significance of carbohydrate dynamics in petal physiology (Evans & Reid, 2022). When flowers are cut, the flow of nutrients and water required for metabolic activities is stopped, which quickly reduces the longevity of flowers when stored at room temperature (Sonego & Brackmann, 1995). Most losses are brought on by the increased plant metabolism, which is related to the consumption of organic substances like carbohydrates, which control cell osmotic potential and function (Doi & Reid, 1995).

During the growth of the petals, a store of polysaccharides is gradually built up, but it is quickly depleted at the start of anthesis to create the osmotic potential that causes the entry of cellular water and leads to bud opening (Evans & Reid, 2022). Moreover, considering that the petal cells require carbohydrates as a respiratory substrate, the decrease in carbohydrate supply throughout the storage period induces events of senescence, which limits the flower vase life.

Typically, after harvest, continuous water uptake and an energy source are necessary for flower opening. In preservative solutions, carbohydrates, particularly sugars, are offered as a nutrition supply and act as a substrate for respiration and osmotic control (Halevy & Mayak, 2011; Van Doorn, 2012). The inclusion of sucrose or glucose in nutrient solutions has been reported to improve various quality parameters such as petal colour and vase life; moreover, they have a positive impact on flower opening in a wide range of flowers (Reid & Jiang, 2012; Van Doorn, 2004).

## **2.7 Enhancing cut-flower vase life**

Given the perishable nature of cut flowers, implementing effective management strategies not only extends their lifespan but also preserves their inherent flower quality and minimizes postharvest losses. Recent advancements in science and technology have significantly improved the agricultural industry and supply chain, contributing to increased profitability. Various methods of enhancing the vase life of

flowers have been proposed (Sharma & Thakur, 2020). This research project is dedicated to identifying practical techniques to provide optimal solutions for both producers and consumers. Emphasis is placed on proper storage practices and the application of preservative solutions.

### **2.7.1 Water**

The quality of the water has an impact on vase life. Due to its high pH (alkalinity), total dissolved solutes (TDS), and hazardous ions, tap water can be harmful for cut flowers (Staby & Erwin, 2022). The quality of the water is expressed in terms of TDS, which shortens the vase life of flowers and fluctuates depending on the presence of water contaminants. (Staby & Erwin, 2022). In addition, a high pH encourages microbial growth, which shortens the cut flower vase life as bacterial colonies can grow in the vascular system resulting in xylem blockage. Acidifying water to a low pH (3.0-3.5) is therefore favourable since it reduces microbial growth and significantly enhances stem water uptake (Van Doorn, 2012).

### **2.7.2 Temperature**

Effective temperature control is crucial in preserving the postharvest quality of cut flowers. Rapid cooling is imperative, as it not only diminishes respiration rates but also curtails metabolic activities (Zhuang et al., 2021). Loyola et al. (2019) emphasized that low temperatures play a pivotal role in reducing total metabolic rates, slowing ethylene production, and impeding the growth of bacteria and fungi during storage or shipment. The recommended storage temperature for most cut flowers is 2 to 3 °C, with exceptions for specific species requiring temperatures above 12 to 16 °C, such as tropical plants (e.g. anthurium), and 4 to 7 °C for cockscomb, oriental lilies, and zinnias (Loyola et al., 2019). Optimal temperatures for different flowers are shown in Table 2.

**Table 2. Examples of optimal temperature demands for different flowers.** Each flower shows the longest longevity when they are stored at the mentioned temperatures (Gupta & Dubey, 2018).

| <b>Flower</b> | <b>Pre-cooling temperature</b> |
|---------------|--------------------------------|
| Anthurium     | 13 °C                          |
| Alstroemeria  | 4 °C                           |
| Gladiolus     | 4 °C                           |
| Rose          | 1- 3 °C                        |
| Carnation     | 1-2 °C                         |
| Gerbera       | 4 °C                           |

Exposure to high temperatures during shipping or storage adversely affects the vase life and quality of cut flowers, and ethylene-sensitive species are more susceptible (Leonard et al., 2011; Rudnicki et al., 1991). For instance, Van Gorsel & Ravesloot, (2019) observed that an 8-hour exposure to 20°C early in the marketing cycle accelerated the opening of *Aster spp.*, *Chrysanthemum spp.*, *Dianthus spp.*, and *Gypsophila spp.* Moreover, a 1-day delay in the marketing chain resulted in a 1 to 3-day decrease in vase life. Consequently, the floriculture sector highlights the need for a temperature-controlled supply chain, including all stages from production to transportation, storage, distribution, and final delivery to customers (Leonard et al., 2011; Reid & Jiang, 2005).

Despite the development of automatic devices to enhance the efficiency of fresh flower logistics, a significant portion of the logistics process has remained manual. This handling often leads to breakdowns in the cold chain, exposing flowers to fluctuating temperatures. However, the positive effects of cooling have been proved (Rudnicki et al., 1991) the establishment of an ideal cold chain demands a substantial initial investment and ongoing expenses, such as fuel and energy (Babalola et al., 2011). That said, cold storage makes it easier to adapt flower stock to market demand.

Menegaes et al. (2023) reported that pre-cooling safflower (*Carthamus tinctorius L.*) stems increase their vase life by up to 12 days when paired with various preservative treatments. To evaluate the impact of precooling, Chalumuru et al. (2014) investigated tuberosa florets alongside four chemical treatments. Observations focused on quality parameters, including floret freshness, colour retention, and physiological weight loss. The study found that precooling could decrease wilting by 50% over the time and extended the flower vase life. Moreover, it is reported that vase life was extended to six days by soaking them in a 4% boric acid solution for two hours.

### **2.7.3 Preservative solutions**

The application of preservative solutions has become common due to their effectiveness in enhancing cut flower longevity. The key postharvest substances are water, sugars, acidifiers, and biocides (Gul et al., 2020).

There are two different types of preservative solutions: i) hydrating solutions are used by florists in the condition stage to help flowers keep uptake water; and ii) holding

solutions, or flower food, are provided to customers to put in the vase water which can be powdery or liquid, they usually contain germicide in addition to sources of sugars. Clark et al. (2010) recommended using a holding solution after hydration with water to have the longest vase life. The study conducted over eight years evaluated 121 cultivars across 47 cut flower genera in the National Cut Flower Trial Program. Stems of promising cultivars were treated with hydrating and holding solutions, revealing distinct postharvest responses. Notably, a holding preservative increased vase life in various genera such as *Ocimum basilicum*, *Rudbeckia hirta*, *Campanula persicifolia*, *Celosia argentea*, *Echinacea purpurea*, and *Helianthus*. However, certain genera experienced reduced vase life with preservative use, including *Eustoma*, *Helenium*, and *Achillea millefolium* (Clark et al., 2010).

A commercial hydrator contains chemicals to lower the pH and improve the uptake of water, as water with a low pH is more easily absorbed by stems than water with a high one (Regan & Dole, 2010). Hydrating solutions do not contain sugar and are not intended to be consumed for a long time (Gul et al., 2020). Commercial-provided solutions have a range of suggested time usage, and this time can vary from some seconds to some days depending on the producer. While a holding preservative is designed to be used for an extended period. They frequently include an adequate amount of carbohydrates, germicides, and an acidifying agent (Halevy & Mayak, 2011).

Chemical substances known as germicides are employed to prevent microbial growth on the surface of the stem and in vase water. Eight-hydroxyquinoline citrate, silver nitrate, aluminium sulphate, citric acid, slow-release chlorine compounds, and quaternary ammonium compounds are significant biocides used to treat cut flowers (Fatima et al., 2022). For example, aluminium sulphate decreases the pH of the solution, efficiently inhibits bacterial development, and causes partial stomatal closure, all of which lengthen flower vase life (Singh et al., 2016).

Various commercial holding solutions, known as flower food, are available in the market that can extend the vase life of flowers with minimal environmental risks. They are user-friendly and can be offered to customers by sellers.

## 2.8 Conclusion

Given the significant costs associated with postharvest hydration and storage, it is common practice to transport cut flowers dry (Kazemi et al., 2018). Although drying management reduces transport and handling costs, it leads to water stress in flowers, evidenced by symptoms like bent necks and wilted leaves. This study aims to address the negative impacts of prolonged drying by investigating the effects of different drying lengths on two cut rose cultivars ('Revival Sweet' and 'Golden Smile') and exploring whether longer hydration lengths can mitigate these effects (Raghuvanshi et al., 2023). Ultimately, the goal is to provide a comprehensive understanding of prolonged drying and propose solutions to enhance vase life, reducing costs and waste in flower maintenance.

While these studies have shown improvements in vase life, they may not be practical in the real supply chain by high costs and an incomplete understanding of the optimal steps for achieving the longest vase life has remained understudied. Addressing this knowledge gap, this study examines the effects of different drying and hydration lengths on cut flower vase life. The aim is to contribute to the development of new methods in the cut flower industry that increase longevity and minimize waste. While previous studies highlight the benefits of immediate postharvest hydrating, this research aims to explore the hypothesis of how prolonged drying reduces cut flower vase life. Additionally, the mitigation of such prolonged dry stress by preservatives, and the ideal timing for flower storage with preservatives remain understudied. Furthermore, there is a lack of microbiological measurements following dry periods, necessitating additional research.

Regardless of the type and cultivar of flowers, water quality and temperature can affect cut flower vase life. There are some suggestions to expand the cut flower vase life such as controlling temperature, improving solution uptake, providing a source of energy, eliminating bacterial growth by application of preservative solutions, and controlling postharvest diseases (Table 3).

**Table 3. The effective factors on cut flower vase life.** Different papers have been summarized to compare and organise all factors in the same place.

| Main factors                            | Role and properties                                                                                                                                                         | Effects                                                                                                                                                         | reference                                                                             |
|-----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| <b>Water</b>                            | pH, ions present, and TDS are important in flower vase life. Lower pH and TDS result in longer vase life.                                                                   | In lower pH microbial presence is less as a result, xylem blockage happens less. TDS lower than 100 mg/l leads to longer vase life.                             | (D. J. Durkin, 2022; Nyakutsikwa et al., 2022; Staby & Erwin, 2022)                   |
| <b>Temperature</b>                      | low temperatures have an important role in reducing total metabolic rates, slowing ethylene production, and reducing bacteria and fungi growth during storage and shipment. | 24-hour pre-cooling period using preservative solutions improves the maintenance of fresh safflower ( <i>Carthamus tinctorius</i> L.) flowers.                  | (Loyola et al., 2019., Menegaes et al., 2023; Ntarella & Kays, 2022)                  |
| <b>Carbohydrate</b>                     | control cell osmotic potential and function as signalling and gene-expression messengers. Sugar gives flowers energy and facilitates their opening.                         | Lack of carbohydrates is one of the main causes of petal senescence. In addition, adding sucrose or glucose to nutrient solutions can improve flower vase life. | (da Costa & Finger, 2016; Jani & Mankad, 2013; Pun & Ichimura, 2003; Van Doorn, 2004) |
| <b>microbial presence in vase water</b> | their colonies can start growing in xylems and block them, as a result, they prohibit water uptake, accelerate wilting, and shorten the vase life.                          | In cut flowers, microbial plugging is typically seen around the base of the stems. Recutting the stems suggested to boots vase life.                            | (De Witte & Van Doorn, 1988; van Doorn et al., 1991, 1995)                            |
| <b>Postharvest diseases</b>             | The two most frequent necrotrophic fungal disease                                                                                                                           | Providing good air circulation in packages and                                                                                                                  | (Dean et al., 2012; Kaur et al., 2023; Öztürk & Bastas, 2022; Muñoz et                |

|                      |                                                                                                                                       |                                                                                                                                                                                                  |                                                                                           |
|----------------------|---------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
|                      | pathogens are <i>Botrytis cinerea</i> and <i>Cladosporium macrocarpum</i> . This microorganism can cause Green and Grey Mold disease. | preventing harvest of the flowers when the leaves are wet are suggested to prohibit diseases and expand vase life.                                                                               | al., 2019; Norman & Ali, 2012; Terry & Joyce, 2004)                                       |
| <b>Preservatives</b> | Preservative solutions facilitate water uptake, limit microbial growth, and provide carbohydrates as a source of energy for flowers.  | The positive effects of preservative solutions have been proven in numerous research. Being environmentally friendly, cost-efficient, and having a high efficiency are important to choose them. | (Asrar, 2012; Fatima et al., 2022; Khan et al., 2015; Knee, 2000; Menegaes et al., 2023a) |

### 3 Material and methods

#### 3.1 Plant material and sample preparation

The examined flower in this experiment was roses. The first experiment was on two different cultivars ('Revival Sweet' and 'Golden Smile') that were cultivated in Kenya, harvested on 27<sup>th</sup> January 2023, and imported by Arena Flowers company (Flowers HQ, Long Bank, Berry Hill, Droitwich, WR9 9AN) flowers were transported dry to the UK in sealed aerated boxes. They were transported to the Plant Science Laboratory at Cranfield University on 28<sup>th</sup> January 2023, where they were kept dry at 5°C. For four days, every 24 hours sampling was done on 10 stems per vase with 4 replicates to have four different drying lengths (24, 48, 72 and 96 hours). Flowers were put in a hydration solution (Chrysal RVB: water, 1:1000, see section 3.3) and kept at 5°C for 24 hours. After that, the stems were recut to a length of 60 cm using pruning shears, while three external petals were removed the lower third of the stems' leaves were peeled and just 2 petioles remained on the stems (florist stage). Flowers were moved to the vases containing flower food (Chrysal Professional2: water, 5:1000) and kept in a variable temperature (VT) room at 18°C and 85% relative humidity mimicking the customer stage for 20 days.

The second experiment was conducted on 'Revival Sweet'. Roses were cultivated in Kenya, harvested on 19<sup>th</sup> August, imported by Arena Flowers company, and received at Cranfield University on 23<sup>rd</sup> August where were kept dry at 5°C. Two different drying lengths were tested (96 and 168 hours). For the first drying, samples were put in the hydration solution when they were received, and the second samples were put in the hydration solution 72 hours later, on 10 stems per vase with 4 replicates. For each sampling point, flowers were put in the hydration solution (Chrysal RVB: water, 1:1000) for 0, 12, 24 and 48 hours at 5°C. Then florist stage was done, and flowers were kept at 5°C for 24 hours (simulating the preparation for delivery done by Arena Flowers). Finally, flowers were moved to the VT room at 18°C and 85% relative humidity in the vases containing flower food (Moonpig: water, 1 sachet: 1 litre) for 18 days.

## 3.2 Experimental design

### 3.2.1 *First experiment: effect of prolonged dry storage on two cultivars of cut roses*

This study tested the impact of prolonged drying on ‘Golden Smile’ and ‘Revival Sweet’ cut roses. Four different drying lengths (24, 48, 72 and 96 hours) in 4 replicates (10 stems per replicate) were tested using a completely randomised design. Two sets of vases were considered, one to measure the appearance changes (percentage of bent necks and damaged flowers) and solution uptake and another one for taking pictures (bud diameter measurements). Figure 4 shows the steps of the first experiment.



**Figure 4. Taken steps during experiment one.** Flowers were kept dry at 5°C, sampling was done every 24 hours for each drying length, in each vase there was 1 litter of tap water with 1 mL Chrysal RVB holding 10 stems of roses for 24 hours. Then stems were cut at 60 cm and extra leaves and 3 external petals were removed, put in vases containing 1 litter of tap water and 5 mL Chrysal Professional 2 and moved to 18°C.

### 3.2.2 *Second experiment: impact of two prolonged dry storage and four hydration lengths on ‘Revival Sweet’ cut Roses*

The second experiment tested the effects of 2 drying lengths (96 and 168 hours) and 4 different hydration lengths (0, 12, 24 and 48 hours) on ‘Revival Sweet’ cultivar (Figure 5). Four replicates (10 stems per replicate) were used within a completely randomised design.

Two different sets of vases for non-destructive (solution uptake, bent necks, damaged flowers) and destructive (colour, bud diameter, sugar concentration in petals were used, and bacterial count and pH in vase water) measurements. To save time,

resources, and examination of the current situation, we just do destructive sampling during the vase life for flowers with 24 hours of hydration (this time of hydration is done in Arena Flowers Company). In addition, on day 18 of the vase life colour, bud diameter, sugar concentration in petals, vase water pH and bacterial presence were measured in all vases.

Samples were chosen to be uniform after delivery when they had been kept dry for 96 hours and sampling for 168 hours of drying was done 72 hours later.



**Figure 5. Taken steps during experiment two.** Flowers were kept at 5°C. After 96 and 168 hours of drying, flowers were put in 1 litre of tap water and 1 mL Chrysal RVB for 0, 12, 24, and 48 hours. After these times, stems were cut at 60 cm and extra leaves and 3 external petals were removed and put in vases containing 1 litre of tap water and 5 mL Chrysal Professional 2. After 24 hours flowers were put in vases with 1 litre of tap water with one sachet of flower food (Moonpig) and moved to 18°C.

### 3.3 Chemicals

#### 3.3.1 Chrysal RVB

Chrysal RVB is a commercially available hydration solution. It is an all-purpose hydration solution with aluminium sulphate intended to work well with a large range of cut flower species including roses. Vascular clogging is decreased when Chrysal RVB flocculates organic matter and hardness in water. It raises the absorption of water, which significantly raises the flower quality (Chrysal, n.d., 2024).

#### 3.3.2 Flower food

Chrysal Professional 2 has been developed for use by wholesalers, bouquet makers, florists, and retailers, in vases and buckets of all cut flowers. It has just the right amount of nutrients to allow flowers to grow naturally without causing them to open too soon. The solution can be used for up to five days, which lessens the need for frequent water

changes. When compared to water alone, it also saves waste by an average of 50% (Chrysal, n.d., 2024).

Flower food sachets (Moonpig) contain a soluble powder that Arena Flowers company offers the customer to use in their vase water. They are produced for the retailer Moonpig (Herbal House, 8-10 Black Hill, London, EC1R 5EN).

The exact ingredient of these commercial provided preservatives is confidential, however, according to the articles they must contain individual sugars, acidifiers, and germicides (Clark et al., 2010; Knee, 2000).

### 3.4 Physical measurements of flower quality

#### 3.4.1 *Damaged flowers*

According to commercial standards, flowers are considered damaged when they have more than 50% of their petals damaged, it is distinguishable by appearing dark signs (discolouration) on the petals (Sarwat & Tuteja, 2019; Tonooka et al., 2023). A healthy flower is compared with a damaged one in Figure 6. By eye examination, the number of damaged roses was counted per vase, percentage of damaged flowers in each vase was recorded.



**Figure 6. Visual assessment - Comparing damaged ‘Revival Sweet’ roses with healthy ones.** Damaged roses from senescence or physical damage with more than 50% damaged petals (top) and healthy roses (down) (photo by Sara Hosseini).

### 3.4.2 *Bent neck*

In roses bent necks arise from a loss of peduncle rigidity (Burdett, 2022). For this assessment flowers were assessed carefully to record the number of those flowers whose necks were bent. A flower-bent neck is shown in Figure 7.



**Figure 7. Comparing roses with and without bent neck.** A stem of ‘Revival Sweet’ Rose with bent neck (right) compared with a healthy one (left) (photo by Sara Hosseini).

## 3.5 Colour and bud diameter

In the first experiment every day for 10 consecutive days, four random flower stems were chosen from the same vases, and pictures were taken using a photo box and a Lumenera INFINITY 3 camera and Infinity Capture Software (version 6.5.7. Lumenera Corporation, Ottawa, Canada). These pictures were used to measure bud diameter using ImageJ software (version 1.54d, National Institutes of Health, Bethesda, MD, USA). The average of four measurements across the surface of the buds were used to obtain bud diameter for each bud, and the average of them was considered for each replicate.

In the second experiment on days 0, 3, 5, 8, 11, 15 and 18 of vase life, destructive sampling was done to measure bud diameter and objective colour in those flowers

that had two drying lengths (69 and 168 hours) and the same hydration length, 24 hours. On the final day of the experiment objective colour and bud diameter were measured in all vases. To take the pictures, five random flower stems were chosen from each replicate using PhotoBox, a Canon EOS 90D DSLR camera and EOS Utility Software (version 3.10.30. Canon Inc., Tokyo, Japan). For consistency, light and camera settings were the same throughout image capture.

To measure the objective colours Red, Green, and Blue (RGB) values of five distinct buds were measured, and their averages were used to analyse the petal colour. To calibrate the RGB values of the petals, the colour chart (ColorChecker, passport photo 2, CCPP2, USA) was used; ImagePro software (version 9.3, Media Cybernetics, Rockville, MD, USA) was used for both normalizing and white balancing the images. Then RGB values were converted in MATLAB software (version R2022b, MathWorks Inc., Natick, MA, USA) to obtain the hue angle ( $h^\circ$ ), chroma ( $C^*$ ), and lightness ( $L^*$ ).

### **3.6 Solution uptake**

To examine the amount of solution uptake (mL per vase), the water level was marked every other day (first experiment), and every three days (second experiment); the volume corresponding to the solution uptake was calculated on the last day of the experiment by putting water back to the vases to each of the level marks recorded during the experiment. Measuring daily solution uptake was done by filling the gaps between days using a syringe. Daily records were added together to have cumulative solution uptake for each vase.

### **3.7 Vase water pH and aerobic colony count**

In the second experiment destructive sampling was done to measure pH and aerobic colony count in vase water of those flowers that had two drying lengths (69 and 168 hours) and the same hydration length, 24 hours on days 0, 3, 5, 8, 11, 15 and 18 of vase life. And on the final day of the experiment aerobic colony count and pH in vase water were measured in all vases.

For these measurements, after taking stems out, vase water was mixed in a shaker. One mL of vase water was taken and added to 9 mL of peptone water, after vortexing the operation was done again in serial dilution until dilution  $10^{-3}$ . One hundred  $\mu\text{L}$  of each dilution was cultured on Petri plates containing Tryptone Soya Agar in three

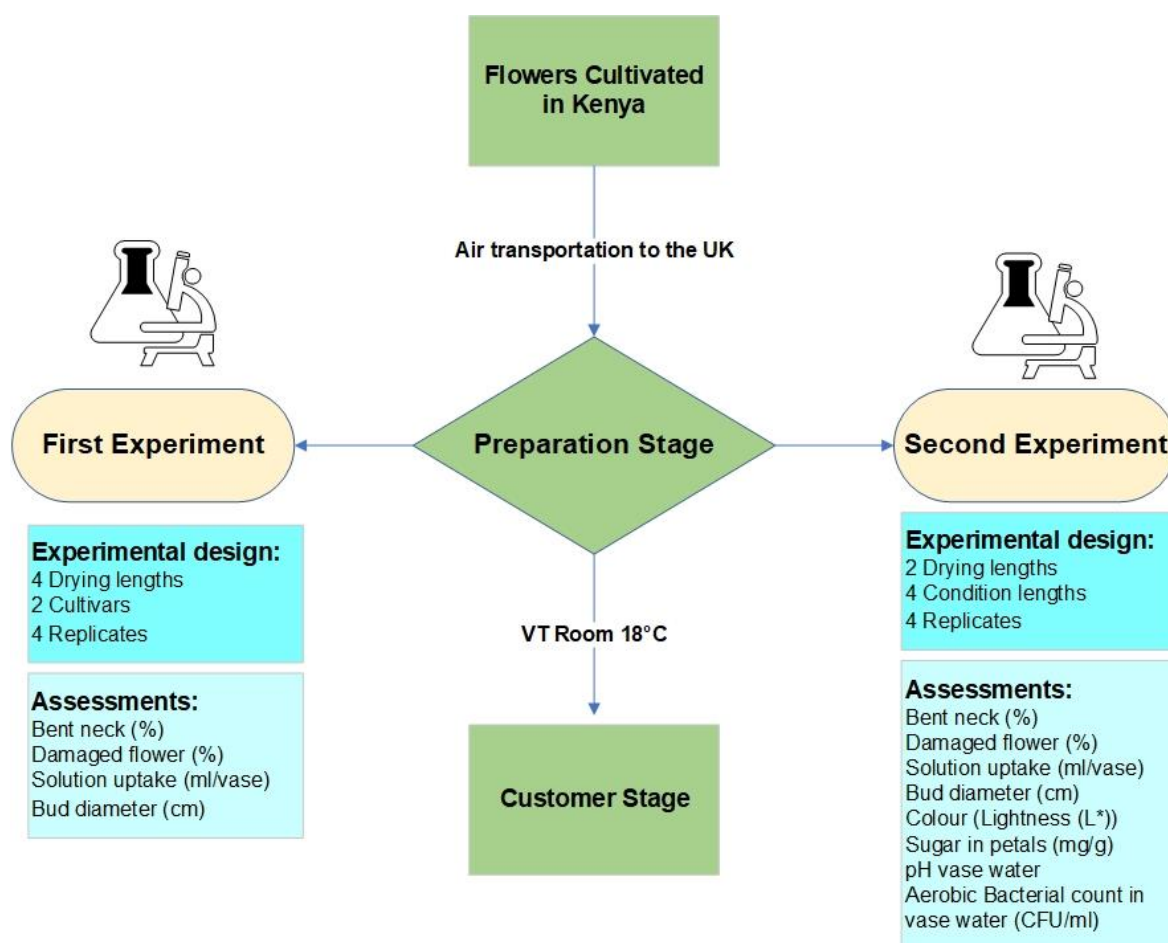
replicates, and the number of colonies was counted after 48 hours at 25°C (Van Doorn et al, 1989), and pH was measured by a JENWAY 3540 pH meter.

### 3.8 Sugar content

Evans & Reid (2022) revealed that fructose, glucose, and sucrose are the primary soluble carbohydrates identified in the petals of rose (*Rosa spp.*) flowers during their rhythmic expansion. Individual sugars were measured in petals for those flowers that had two drying lengths (69 and 168 hours) and the same hydration length, 24 hours on days 0, 3, 5, 8, 11, 15 and 18 of vase life. In addition, individual sugars were measured in the petals of all flowers on the final day of the experiment.

Five random stems were taken from each replicate and half of their petals snap frozen in liquid nitrogen before freeze drying at -52°C for 7 days. Freeze-dried material was ground to a fine powder using an electrical blender. Individual sugars (glucose, fructose, and sucrose) were extracted from  $50 \pm 1.5$  mg dry weight (DW) of roses petal powder in 3 mL of extraction solvent (62.5:37 methanol: water V/V) and mixed properly. Samples were placed in a low-speed shaking water bath at 55°C for 15 minutes. During this time, samples were vortexed for 20 seconds every 5 minutes. When samples were cooled down, they were filtered through 0.2 µm nylon syringe filters into clear (Agilent) HPLC vials. Samples were injected into an Agilent 1260 HPLC system (Agilent Technologies LDA UK Ltd., Cheshire, UK, and Agilent Chemstation software version 4) coupled with an evaporative light scattering detector (ELSD). Standards for individual sugars were used to prepare a calibration curve with the following concentrations 0.2, 0.4, 0.6, 0.8, 1.0 and 5.0 mg/mL. A Rezex TM RCM-Monosaccharide Ca+ 300 × 7.8 mm column was used as the stationary phase. Ultrapure water was used as the mobile phase for HPLC analysis. The flow rate was set to 1 mL/min and the autosampler injection volume was set to 20 µL.

Figure 8 summarises the experimental designs and assessments of the two experiments.



**Figure 8. Summary of the experiments.** The first experiment examined the effects of prolonged dry storage on two cultivars of cut roses, bent necks (%), damaged flowers (%), solution uptake (mL/vase) and bud diameter (cm) were measured. The second experiment examined the impacts of two prolonged dry storage and four hydration lengths on Revival Sweet cut Roses, bent necks (%), damaged flowers (%), solution uptake (mL/vase), bud diameter (cm), colour, sugar content in petals (mg/g), vase water pH and aerobic bacterial count (CFU/mL) were done.

### 3.9 Statistical analysis

Statistical analyses were run using Genstat for Windows 23<sup>rd</sup> edition (VSN International Ltd, Herts., UK). Analysis of variance (ANOVA) was used to determine whether factors (drying length, vase life [day], hydration length) and their interactions significantly impacted the attributes under study. The Least Significant Difference (LSD;  $P = 95\%$ ) was obtained with a 5% risk to identify the differences between the main factors and their interactions. ANOVA tables are available in the appendices section. SigmaPlot for Windows SPW13 (Systat Software, Inc., London, UK) was used to create all plots.

## 4 Results

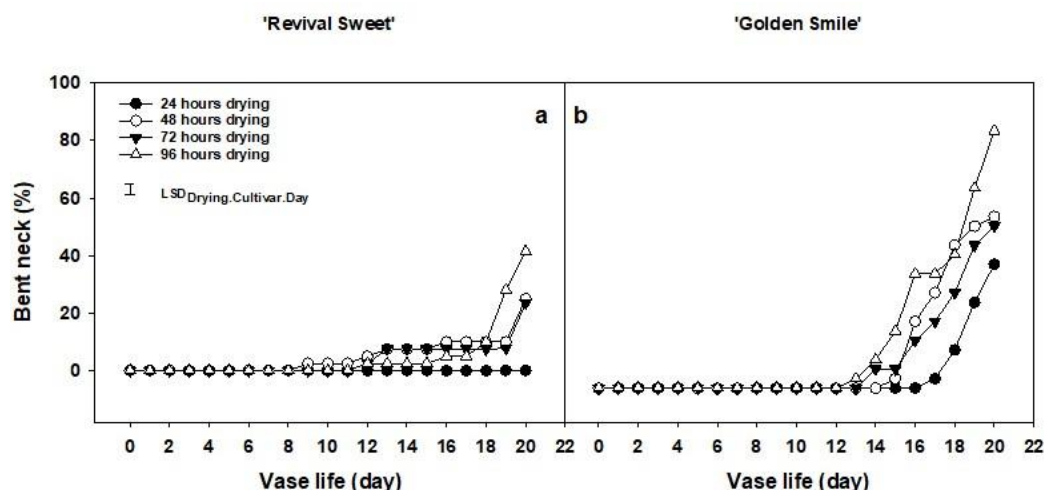
### 4.1 First experiment: effects of prolonged dry storage on two cultivars of cut roses

#### 4.1.1 *Bent neck*

There were significant differences in the percentage of bent necks between 'Golden Smile' and 'Revival Sweet' cultivars on different days and drying lengths (Table 4). That said, on the final days of the experiment the highest percentage of bent necks was observed in roses subjected to prolonged drying (96 hours), in both cultivars (Figure 9).

In 'Revival Sweet', there was no bent neck in flowers that had been kept dry for 24 hours after 20 days. Drying for 24 hours in 'Golden Smile' resulted in neck bending starting after day 14 and reaching ca. 35% on day 20. In 'Revival Sweet' there was no significant difference between 48 and 72 hours of drying; although in 'Golden Smile' difference between these two drying lengths was significant, where 48 hours of drying resulted in a higher percentage of bent necks from day 16 onwards compared than 72 hours of drying. Those flowers that experienced 96 hours of drying started bending on days 12 and 13, for 'Golden Smile' and 'Revival Sweet' respectively.

In addition, in both cultivars, flowers had no bent neck until day 8 for all drying lengths. On the final day of the experiment considering all drying lengths together, 46.87% of 'Golden Smile' and 28.12% of 'Revival Sweet' were bent.



**Figure 9. Changes in the bent necks in cut roses (%) during the vase life (day).** The percentage of bent necks was analysed in **(a):** 'Revival Sweet' and **(b):** 'Golden Smile' roses which were kept at 18°C for 20 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying length x cultivar x day has been shown where appropriate.

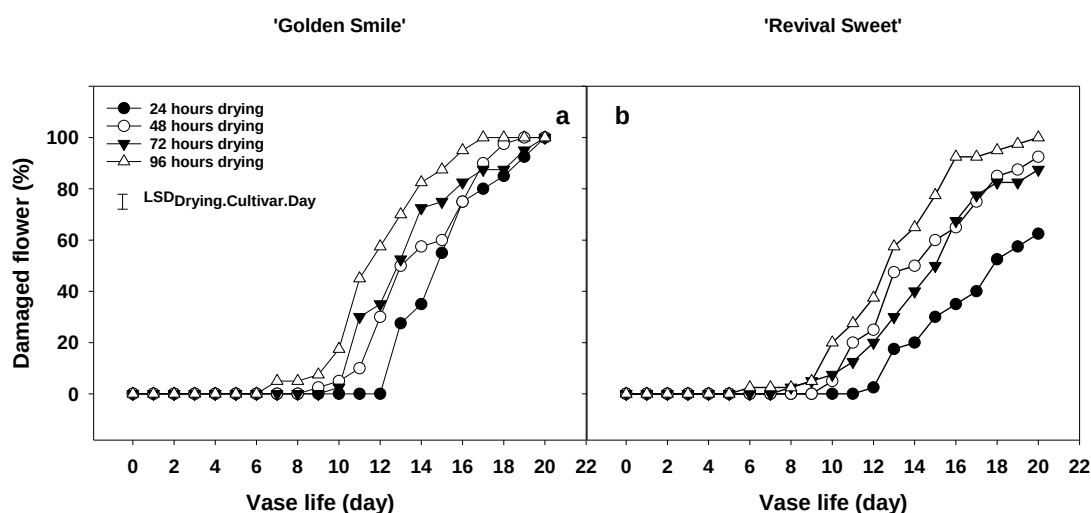
#### 4.1.2 Damaged flowers

The percentage of damaged flowers increased with increasing drying storage time in both cultivars. There was a significant difference between two different cultivars, 4 drying lengths, and 20 days (Table 5).

During the vase life, there was a significant distinction in damaged flowers between the 'Golden Smile' and 'Revival Sweet' considering all drying lengths, with 'Revival Sweet' being more resistant to damage. 'Golden Smile' flowers started showing damage symptoms on day 7 and 'Revival Sweet' on day 6 which started with those flowers that had been kept dry for 96 hours in both cultivars.

At the end of the experiment, in 'Golden Smile', 100% of all flowers were damaged although in this cultivar 24-hour drying there had been no significant signs of damage by day 12. In 'Revival Sweet', flower damage appeared with the longer drying length (96 hours) on day 6 and reached 100% on the final day. In this cultivar, 24 hours of drying started showing damaged symptoms on day 12 and on the final day of the experiment, 62.5% of these flowers were damaged. Generally, by expanding drying storage time from 24 to 96 hours, the percentage of damaged flowers rose by 37.5% at the end of the vase life.

In both cultivars, 96 hours of drying had a significant difference with other treatments from day 10 to 19. At the end of the experiment, 'Golden Smile' roses exhibited complete damage across all drying durations, while 'Revival Sweet' roses showed 55% damage with 24 hours of drying, increasing to 97.5% after 96 hours of drying.



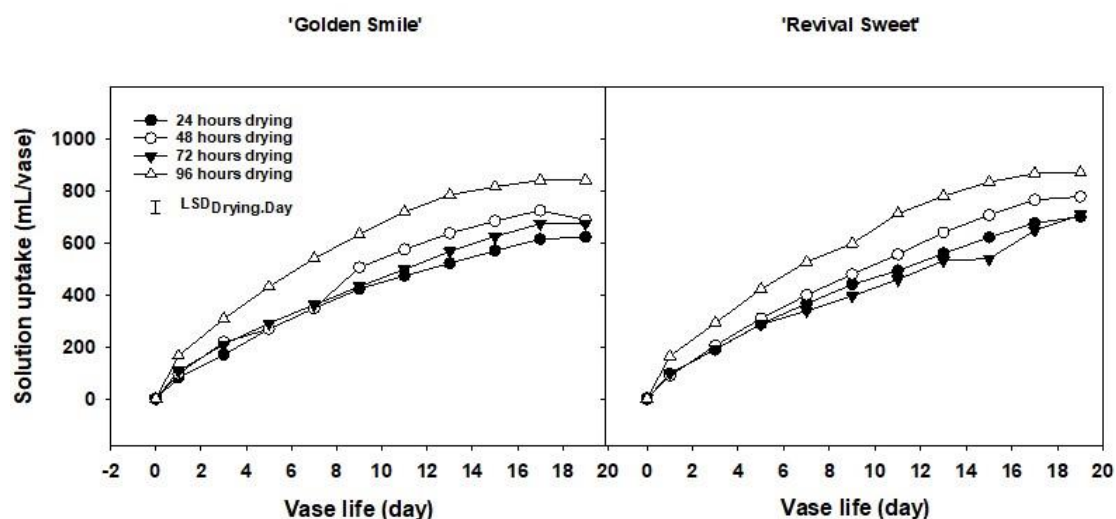
**Figure 10. Changes in damaged flowers (%) in cut roses during the vase life (day).** The percentage of damaged flowers was analysed in (a): 'Golden Smile' and (b): 'Revival Sweet' roses which were kept at 18°C for 20 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying x cultivar x day has been shown where appropriate.

#### 4.1.3 Solution uptake

Overall, the interaction between the two cultivars was found to be insignificant. On average, each vase of 'Golden Smile' absorbed 443.5 mL, while each 'Revival Sweet' vase took 446.2 mL. although the the difference between two cultivars was not statistically significant, the interaction of drying lengths and cultivars was significant (Table 6). According to the results, longer drying storage results in higher amounts of solution uptake. As time passed cumulative solution uptake increased although the slope of the graphs decreased, which means daily solution uptake had a reverse relationship with the number of days that flowers were at 18°C (Figure 11).

Those flowers that were kept dry for 96 hours had the highest cumulative solution uptake and it had a significant difference with other drying lengths. However, results indicated that there was no significant difference in drying storage for 24 or 72 hours from the first to the last day. According to the analysis, in the 48- and 96-hour

treatments, the daily solution uptake was extremely low between days 17 and 19. Additionally, there was no significant difference between the 48-hour treatment and the 24- and 72-hour drying treatments until day 5, after which the difference steadily rose until day 17 and then declined.



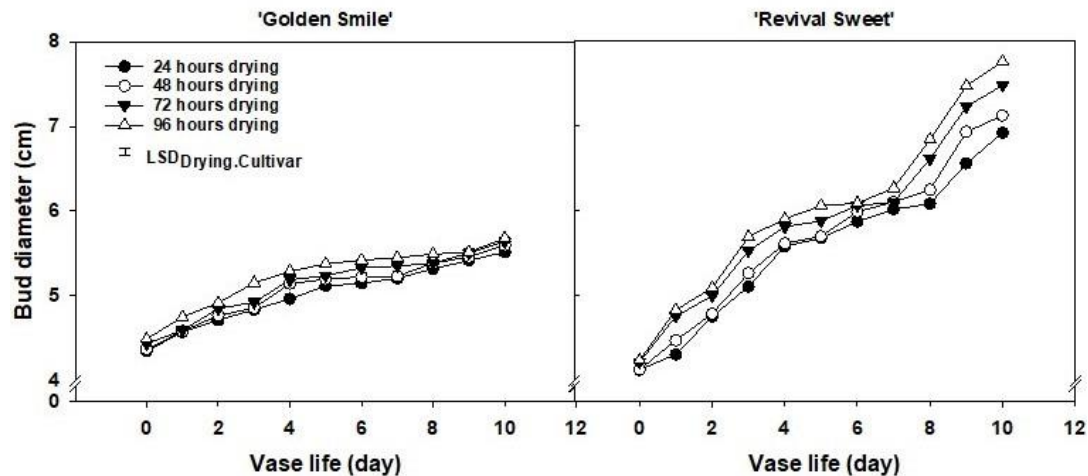
**Figure 11. Cumulative solution uptake in cut roses (mL/vase) during the vase life (day).**

The bud diameter was analysed in 'Revival Sweet' and 'Golden Smile' roses which were kept at 18°C for 20 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying  $\times$  day has been shown where appropriate.

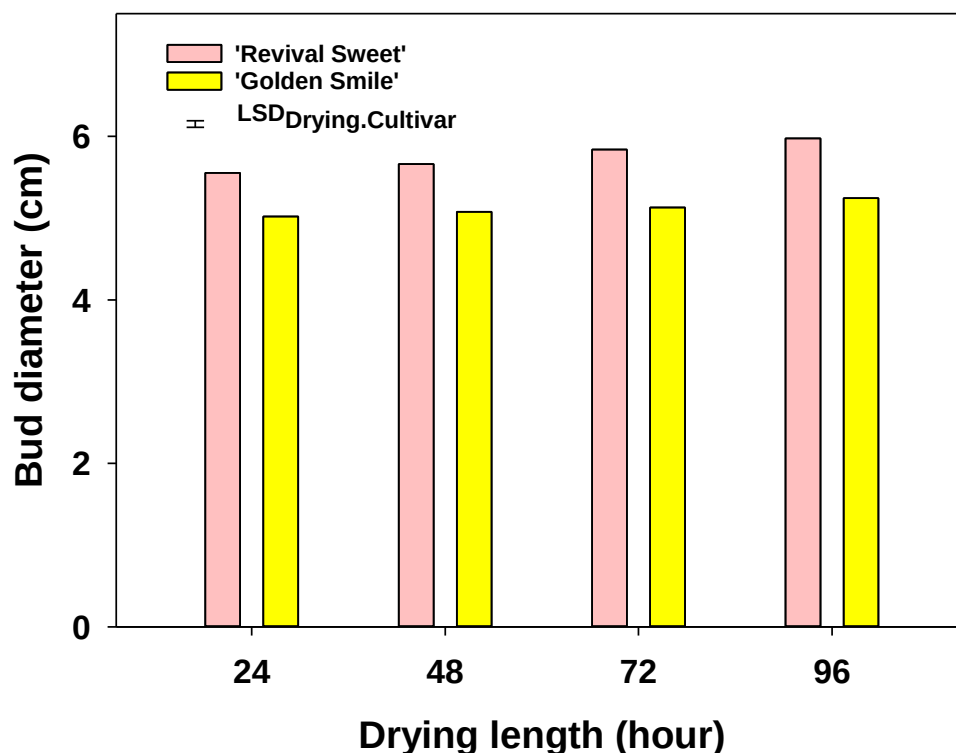
#### 4.1.4 Bud diameter

The variation in bud diameter was found to be significant across different drying lengths, cultivars, and days. In both cultivars, the bud diameter rose significantly as the drying duration extended from 24 to 96 hours (Figure 13). Additionally, the interaction between drying length and cultivar, as well as between cultivar and day, was significant. However, the interaction between drying length and day was deemed insignificant (Table 7). 'Revival Sweet' opened more than 'Golden Smile' and had a bigger diameter over time, while the diameter of the flower on the first day of measurement, 'Golden Smile' was bigger than 'Revival Sweet'. Bud diameters in both cultivars increased over time, but this growth in 'Revivals Sweet' was significantly more than in 'Golden Smile', as after 10 days, 'Revival Sweet' bud diameter almost doubled, from ca. 4 to 7.5 cm (Figure 12). 'Golden Smile' flowers became approximately 5.5 cm from approximately 4.5 after 10 days.

...



**Figure 12. Changes in bud diameter in cut roses (cm) during the vase life (day).** The bud diameter was analysed in (a): 'Golden Smile' and (b): 'Revival Sweet' roses which were kept at 18°C for 20 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying x cultivar has been shown where appropriate.



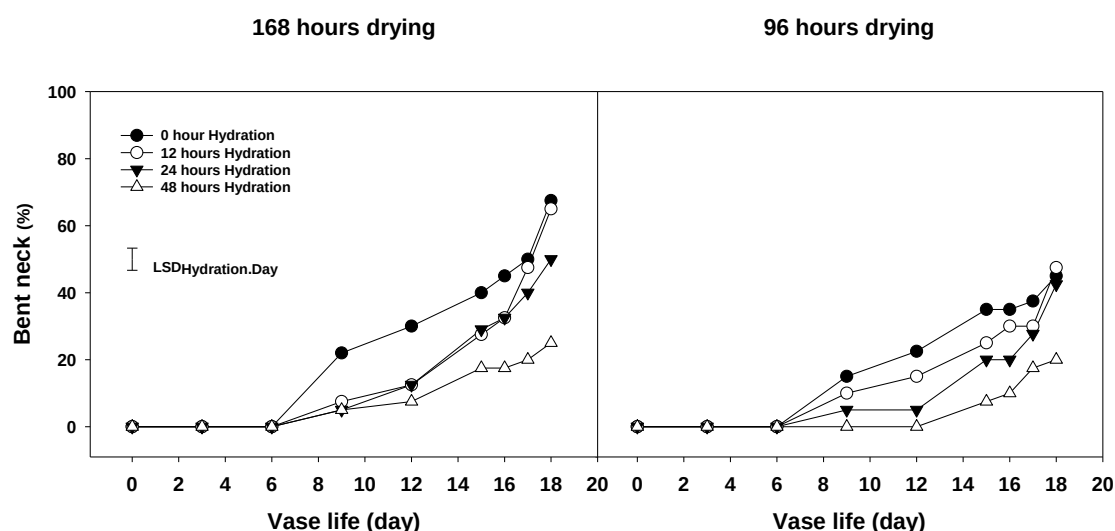
**Figure 13. Changes in bud diameter in cut roses (cm) for different drying lengths on day 10 of the experiment.** The bud diameter was analysed in 'Golden Smile' and 'Revival Sweet' roses which were kept at 18°C for 20 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying length x cultivar has been shown where appropriate.

## 4.2 Second experiment: impacts of two prolonged dry storage and four hydration lengths on 'Revival Sweet' cut Roses

### 4.2.1 Bent neck

The percentage of bent necks increased over time. There was a significant difference between drying lengths as longer drying lengths resulted in a higher percentage of bent necks. In both drying lengths, by expanding the hydration lengths percentage of bent necks decreased. In addition, the interactions of days with drying and hydration lengths were significant but the interaction of drying and hydration lengths was insignificant (Table 8).

There was no bent neck by day 6 of vase life. The highest percent of bent necks was seen in flowers with no hydration as by the end of the experiment they had approximately 65% and 40% of the bent necks for 168 and 96 hours of drying respectively. Flowers that underwent 48 hours of hydration showed bent necks on day 12 for those subjected to 96 hours of drying, and on day 9 for those subjected to 168 hours of drying. Flowers with no hydration had ca. 66% more bent necks compared to 48 hours of hydration (Figure 14). After 18 days, less than 40% of flowers that had 48 hours of hydration in both drying lengths showed bent necks.



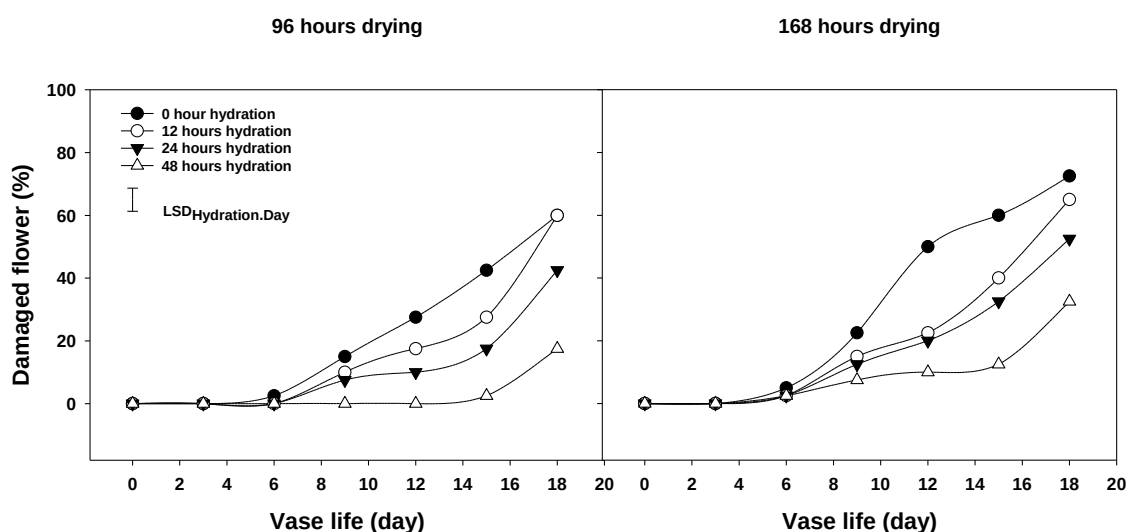
**Figure 14. Changes in the bent necks in cut roses (%) during the vase life (day).** Flowers with bent necks were counted in each vase. Flowers with two different drying lengths (96 and 168 hours) and had 4 hydration lengths (0, 12, 24 and 48 hours) that were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions hydration length  $\times$  day has been shown where appropriate.

### 4.2.2 Damaged flowers

The percentage of damaged flowers declined as they had a longer hydration, and those that had a longer drying time showed more signs of damage (Figure 15).

Significant differences were seen between drying lengths as well as between hydration lengths and days. Additionally, the day's interaction with drying and hydration lengths was significant, but the interaction between drying and hydration lengths was not (Table 9).

At the end of the experiment, no hydration and 168 hours of drying resulted in the highest percentage of damaged flowers; 72.5% of flowers were damaged. Forty-eight hours of hydration decreased the percentage of damaged flowers, while after 18 days, only ca. 30% of roses had been damaged. By expanding the hydration length from 0 to 48 hours, the percentage of damaged flowers decreased by 75%.

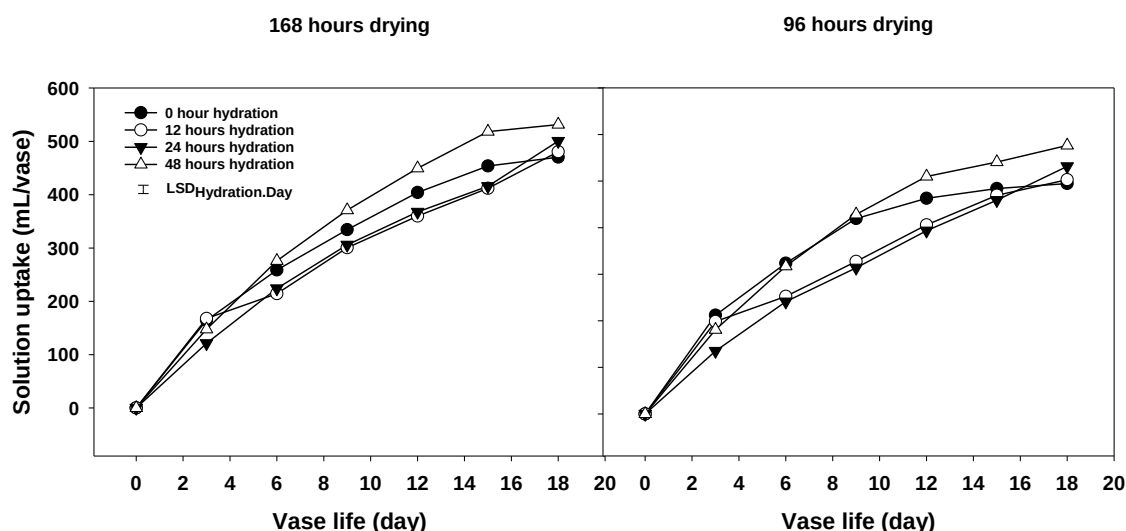


**Figure 15. Changes in damaged flowers (%) in cut roses during the vase life (day).** Flowers with more than 50% damaged petals were counted in each vase. Flowers with two different drying lengths (96 and 168 hours) and had 4 hydration lengths (0, 12, 24 and 48 hours) that were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions hydration length x day has been shown where appropriate.

### 4.2.3 Solution uptake

During the vase life, solution uptake in flowers with varying drying and hydration was significantly different (Table 10). Cumulative solution uptake in flowers with 168 hours

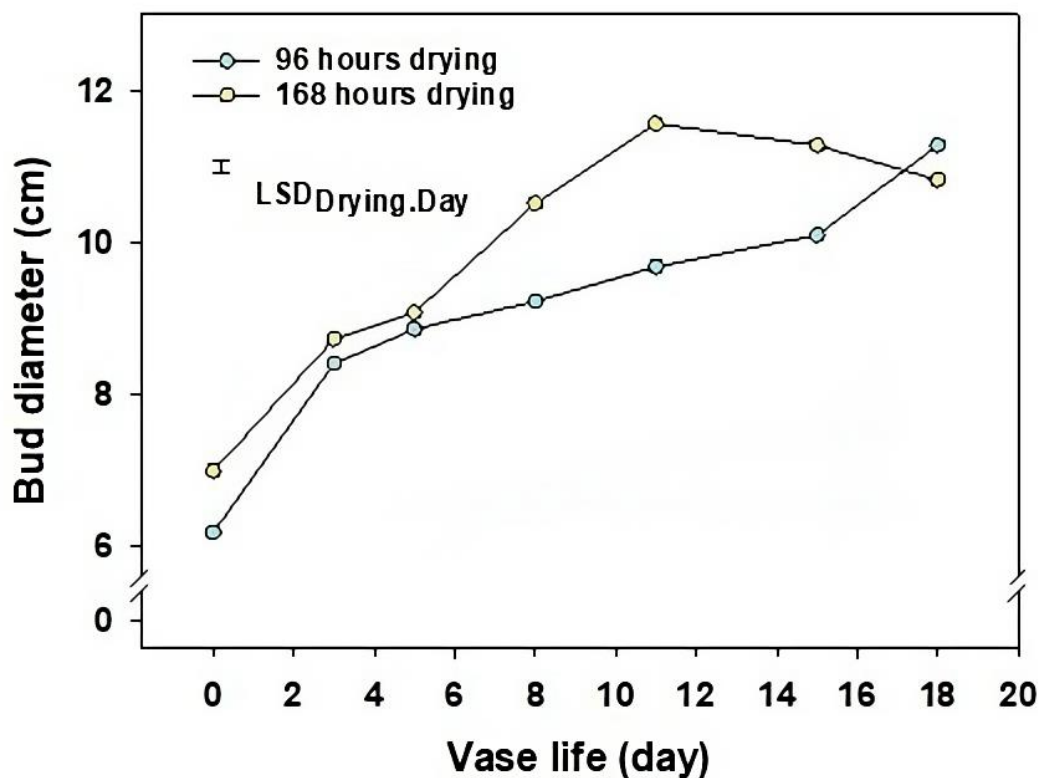
of drying was higher than those that experienced 96 hours of drying, and by expanding hydration length cumulative solution uptake increased and daily solution uptake (the slope of the cumulative graph) was higher in this treatment (Figure 16). The difference in the amount of solution uptake between the longest and shortest hydration lengths, 0 and 48 hours, in 168 hours of drying was ca. 150 mL per vase. In addition, there was no significant difference between 12 and 24 hours of hydration.



**Figure 16. Cumulative solution uptake in cut roses (mL/vase) during the vase life (day).** Flowers with two different drying lengths (96 and 168 hours) of drying with 4 hydration lengths (0, 12, 24 and 48 hours) were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions hydration length  $\times$  day has been shown where appropriate.

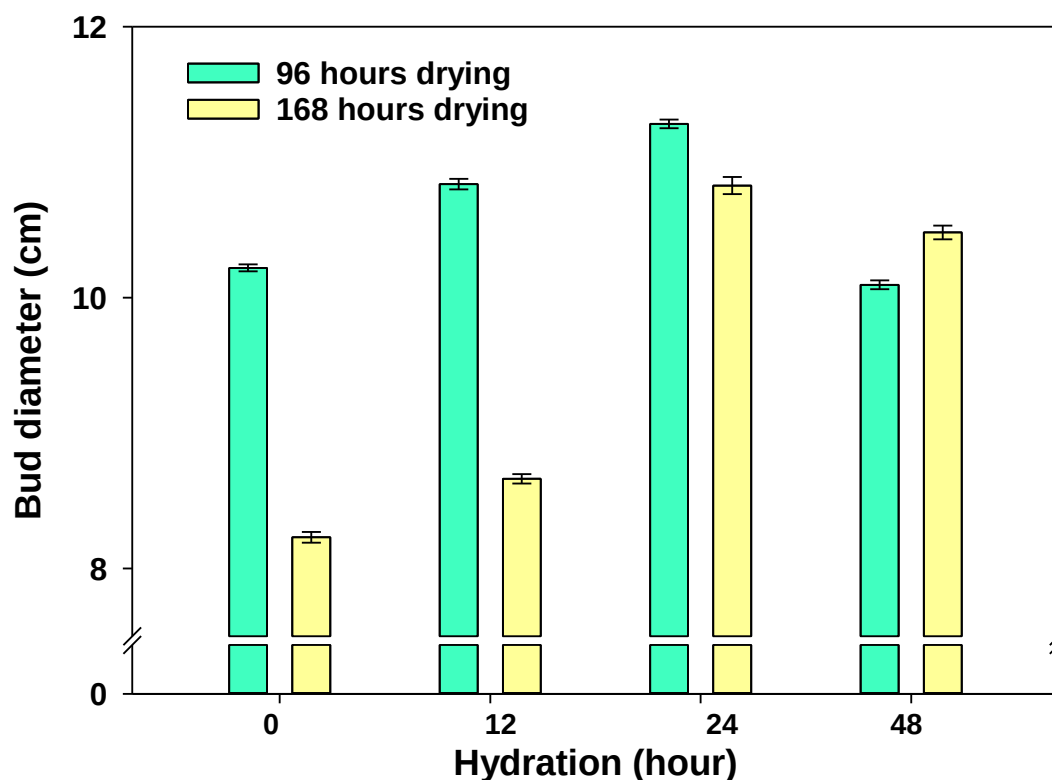
#### 4.2.4 Bud diameter

Bud diameter of flowers subjected to the same hydration length (24 hours) but different drying lengths (96 and 168 hours) were examined throughout their vase life. Significant differences in bud diameter were observed between drying and days (Table 11). In 168 hours of drying flowers opened at a faster speed and reached a peak at approximately 11.7 cm on day 11 of vase life and showed signs of decrease after that. Shorter drying length, 96 hours, resulting in a growth in bud diameter to overtake flowers with 168 hours of drying and reach ca. 11.5 cm on day 18 (Figure 17).



**Figure 17. Changes in bud diameter in cut roses (cm) during the vase life (day).** The bud diameters were measured for flowers with two different drying lengths (96 and 168 hours) and 24 hours of hydration that were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions Drying length x day has been shown where appropriate.

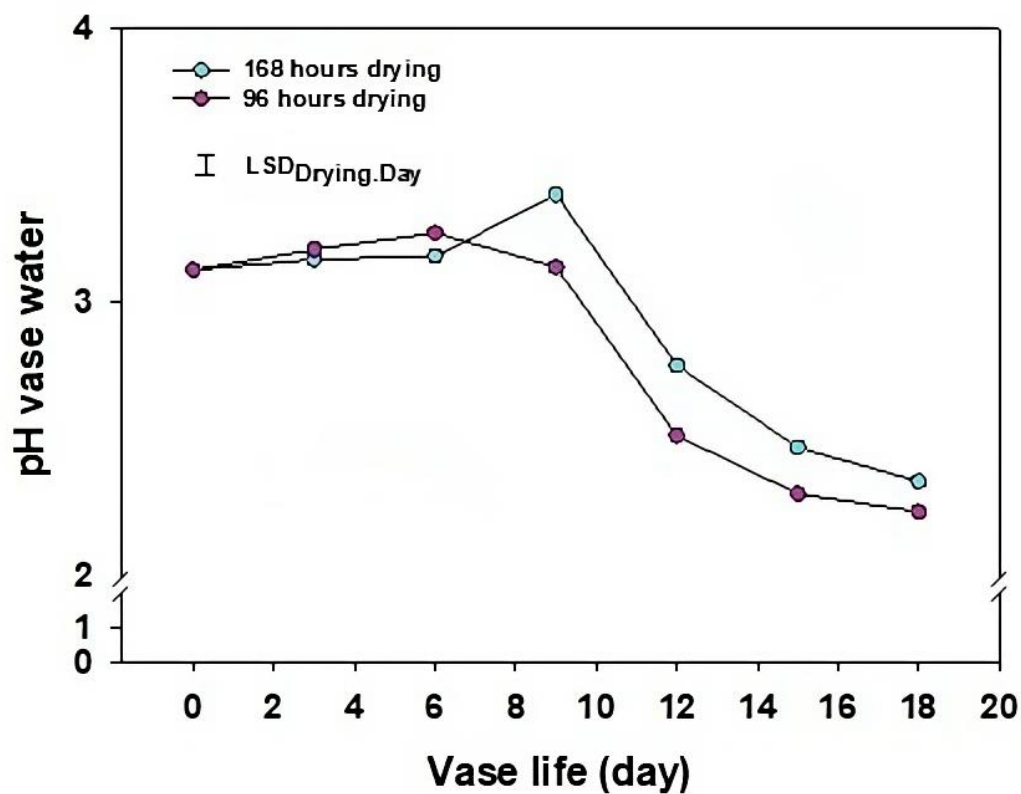
On the final day of the experiment, bud diameter was measured for all flowers. Overall, bud diameters in different drying lengths with the same hydration length were significantly different (Table 12). Flowers with no hydration and 168 hours of drying showed the smallest bud diameter of 8.23 cm while bud diameter in 0 hydration and 96 hours of drying was 10.84 cm. Twenty-four hours of hydration showed the biggest bud diameter on day 18 at 11.28 and 10.83 cm for 96 and 168 hours of drying respectively. In 48 hours of hydration, two different drying lengths showed the least differences in bud diameter by a difference of less than 0.5 cm (Figure 18).



**Figure 18. Bud diameter in cut roses (cm) with different drying and hydration lengths on day 18 of the vase life.** The bud diameters were measured on the last day of the experiment for flowers with 2 drying lengths (96 and 168 hours) and 4 hydration lengths (0, 12, 24 and 48 hours) that were kept at 18°C for 18 days. Error bars represent standard deviation.

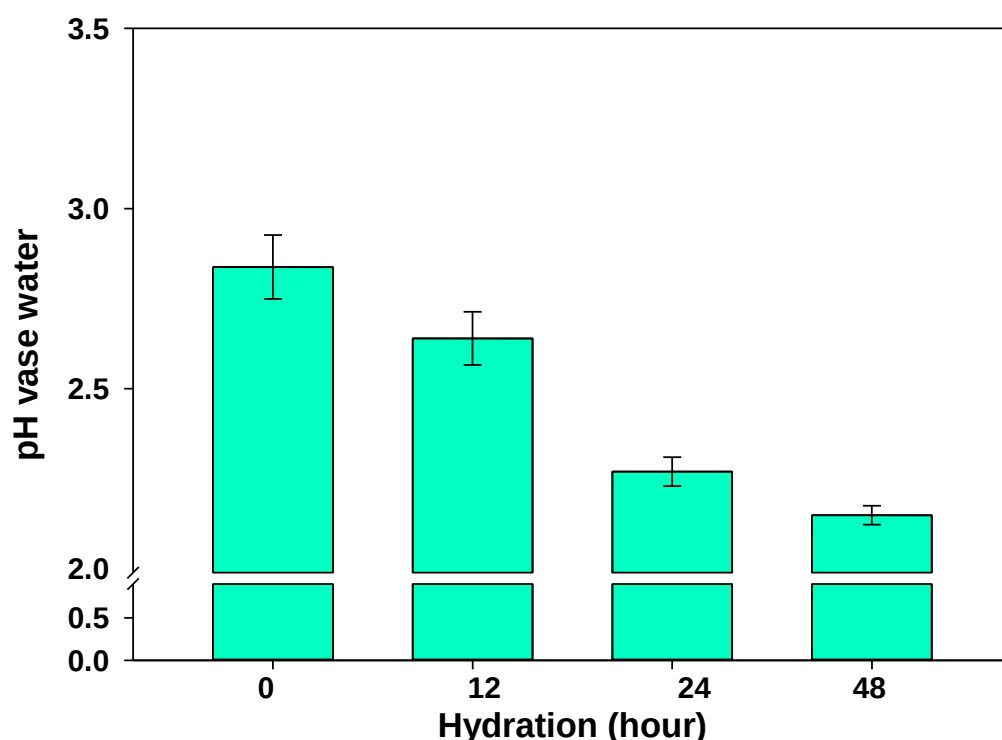
#### 4.2.5 pH

During vase life, the pH of the vase water of flowers with 24 hours of hydration and different drying lengths (96 and 168 hours) was measured, and the interaction of drying length and day showed significant differences (Table 13). On day 0, before putting the flowers in, the vase water pH was 3.12 (Figure 19). From day 1 to 6, the pH slightly increased. The vase water of flowers that had a longer drying length was lower, although this difference is not significant. From day 7 to 18 the pH decreased and the pH of the vase water of the flowers with 168 hours of drying length was significantly higher than those that experienced 96 hours of drying. However, this difference was not significant by the end of the experiment.



**Figure 19. Vase water pH in cut roses during the vase life (day).** The pH of flower vase water was analysed for two different drying lengths (96 and 168 hours) which both had 24 hours of hydration length and were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying length x day has been shown where appropriate.

On the final day of vase life, vase water pH was measured in all vases with different drying and hydration lengths (Figure 20). There was no significant difference between the two drying lengths although the difference between hydrations was significant (Table 14). Vase water with those flowers experiencing longer hydration time (24 and 48 hours) showed almost 38% lower pH than those without hydration at the end of the experiment, and by 12 hours of hydration, the vase water pH decreased by 22% on day 18.

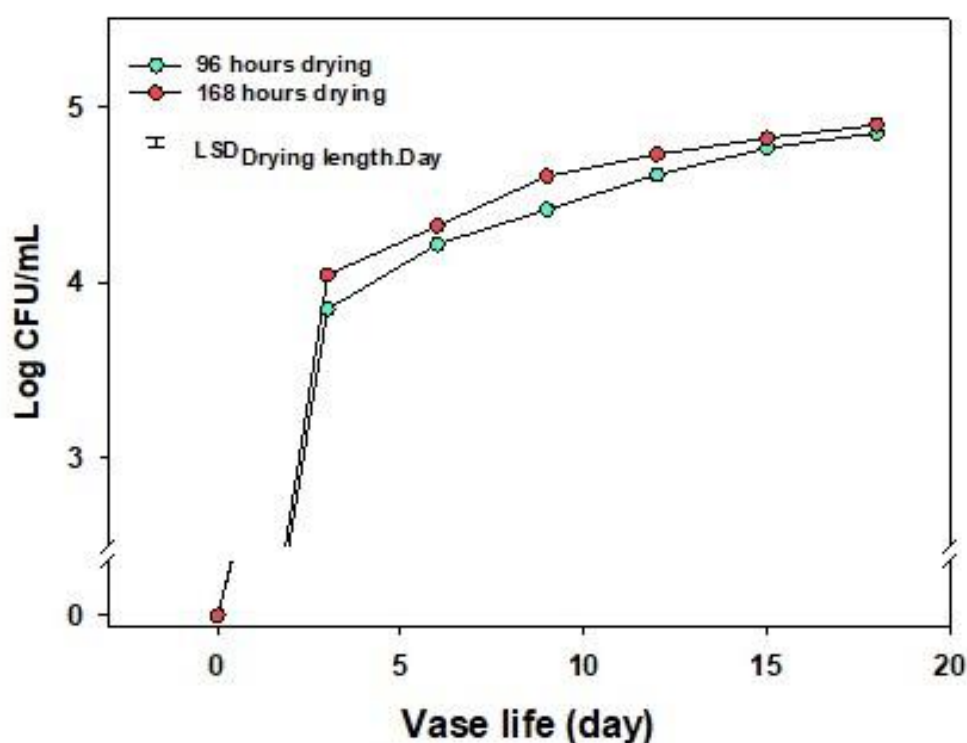


**Figure 20. Vase water pH in cut roses with different hydration lengths on day 18 of the vase life.** The pH of flower vase water was analysed for two different drying lengths (96 and 168 hours) which had 0, 12, 24 and 48 hours of hydration and were kept at 18°C for 18 days. Error bars represent the standard deviation.

#### **4.2.6 Aerobic colony count**

Vase water of flowers with 96 and 168 hours of drying followed by 24 hours of hydration were examined over time for aerobic colony count. The interaction of drying lengths and days was significant (Table 15). CFU stands for colony formation units.

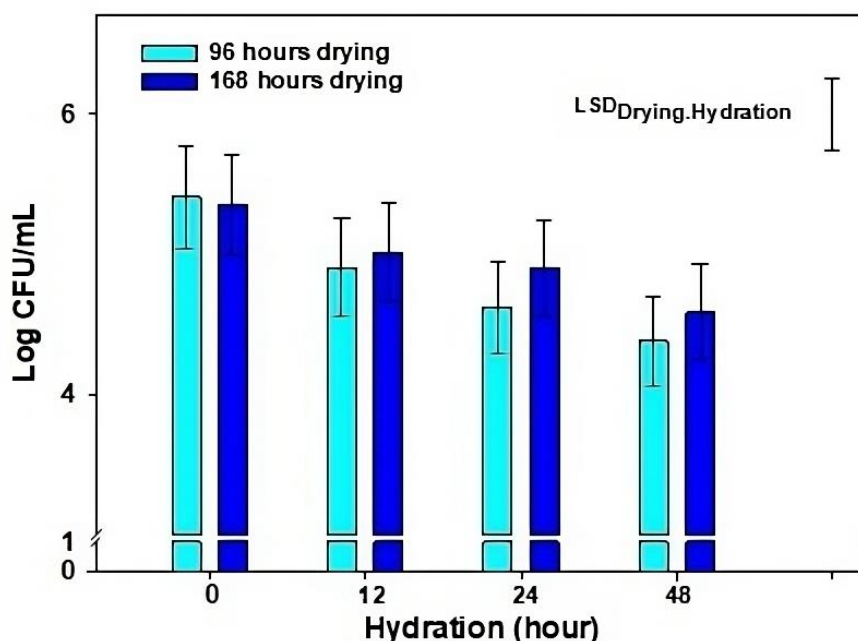
On day 0 before putting the stems in the vases, there were too few colonies to count ( $\leq 100$  CFU/mL est.) in the vase water combined with one sachet of flower food (Moonpig), but the CFU increased during the time (Figure 21). On day 3, flowers with 168 hours of drying had ca. 5% more total aerobic colony populations than flowers with 96 hours of drying. A significant difference in the number of CFU/mL was seen between day 3 and day 12 for two drying lengths, however, after day 12 significant difference between two drying lengths was not seen.



**Figure 21. Total aerobic colonies plate count in vase water of cut roses during the vase life (day).** The aerobic colonies were counted in the vase water of flowers with two different drying lengths (96 and 168 hours) which both had 24 hours of hydration length and were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the interactions drying length x day has been shown where appropriate.

On day 18 of the vase life, the concentration of aerobic colonies was determined in the vase water of flowers with different drying and condition lengths, the interaction of drying and hydration was significant (Table 16).

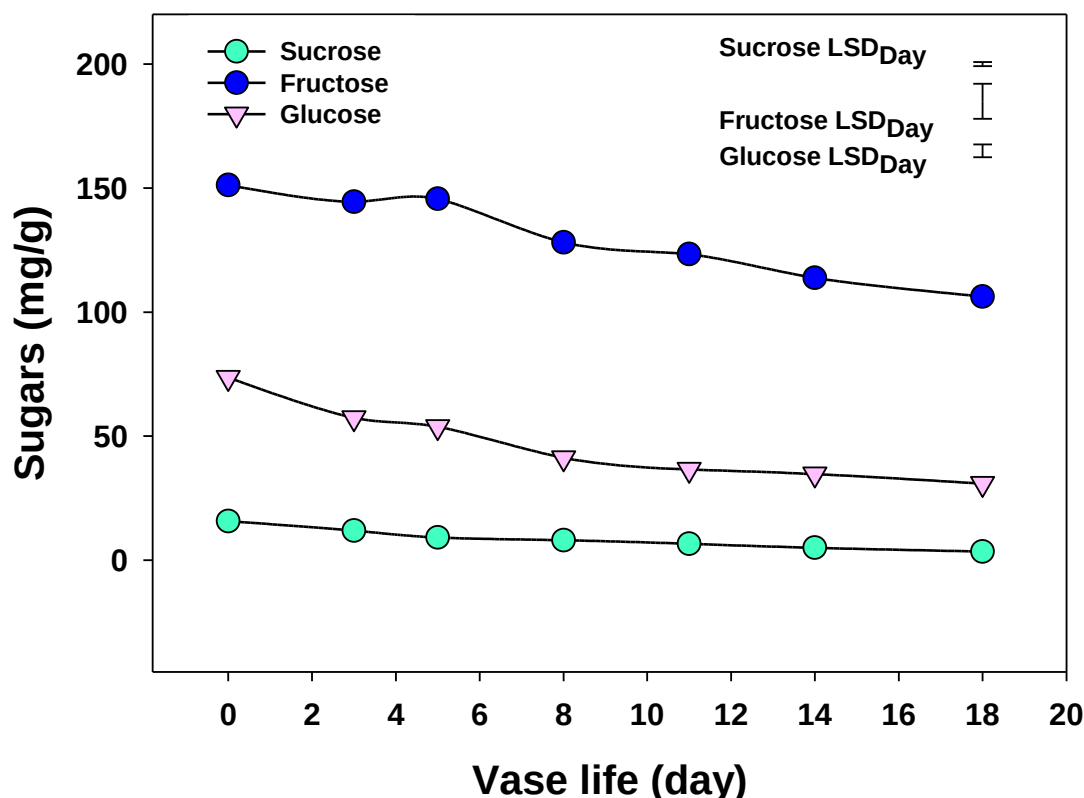
The vase water of flowers with 96 hours of drying had lower total aerobic counts than those with 168 hours of drying, significant differences in aerobic counts were seen in vase water of flowers with 48 hours of hydration and those with no hydration (Figure 22). Flowers without hydration had a significantly larger total aerobic counts in the vase water, whereas 48 hours of hydration resulted in the smallest concentration of CFU/mL. By expanding the hydration time from 0 to 48 hours, the CFU/mL in the vase water was decreased by ca. 17% on the final day.



**Figure 22. Total aerobic count in vase water of cut roses on the final day of the experiment.** On day 18, the aerobic colony count was evaluated in the vase water of flowers with two different drying lengths (96 and 168 hours) which had different hydration lengths (0, 12, 24 and 48 hours) and were kept at 18°C for 18 days. Error bars represent the standard deviation. Least significant difference (LSD) ( $p < 0.05$ ) bars for the interactions drying length x hydration length have been shown where appropriate.

#### 4.2.7 Sugar concentration

Individual sugar (glucose, fructose, and sucrose) concentration was measured in petals of flowers with 2 drying lengths (96 and 168 hours), and 24 hours of hydration during the vase life. The concentration of all three individual sugars significantly decreased over time (Figure 23). No significant differences were seen between two drying lengths (Table 17). The concentration of glucose and fructose did not differ significantly across drying lengths. However, flowers subjected to 96 hours of drying exhibited a significantly higher sucrose concentration of 9.11 mg/g sucrose compared to those kept dry for 168 hours which had a concentration of 7.97 mg/g.

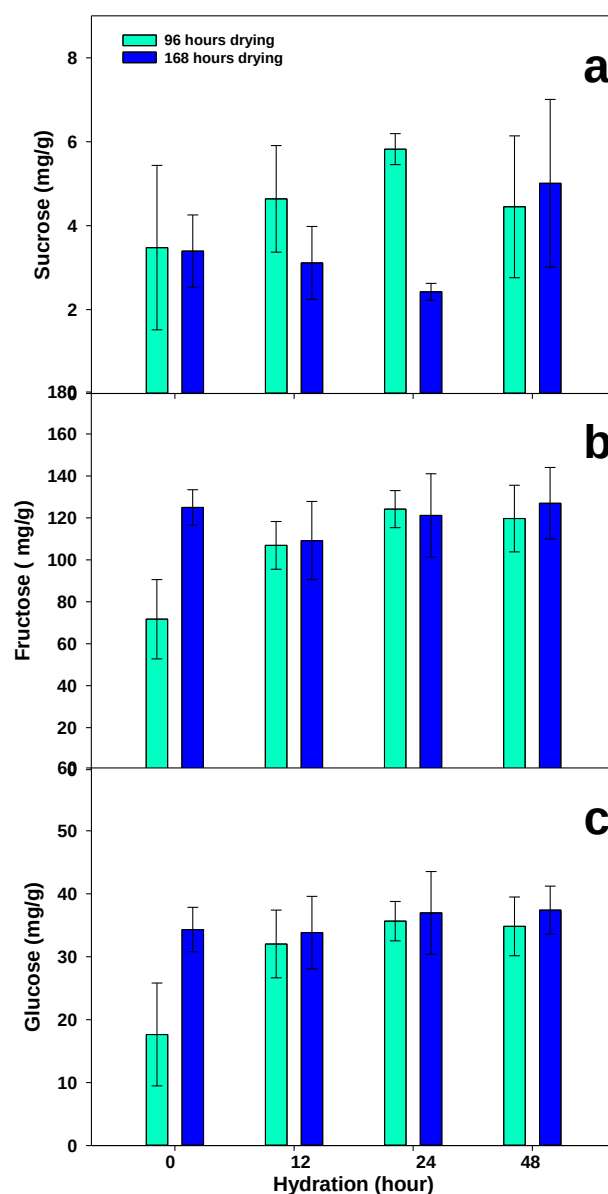


**Figure 23. changes in individual sugar (glucose, fructose, and sucrose) concentration during the vase life (day).** The concentration of individual sugar was measured in the petals of flowers with two different drying lengths (96 and 168 hours), both of which underwent 24 hours of hydration and were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for the day has been shown where appropriate.

On the final day of vase life, the concentration of individual sugars (glucose, fructose, and sucrose) was measured (Figure 24). For all three types of sugars, differences among hydration and drying lengths and their interactions were statistically significant (Table 18).

Flowers with 96 hours of drying had significantly higher sucrose content than flowers having 168 hours of drying except for 48 hours of hydration. That said, the difference between drying lengths in this treatment was not significant (Figure 24-a). The concentration of sucrose in flowers that had been dried for 96 hours and hydrated for 24 hours was statistically like that of flowers that had been dried for 168 hours and then hydrated for 48 hours. Flowers with 168 hours of drying with 48 hours of hydration had the highest concentration of sucrose in their petals.

On the final day of vase life, no significant differences between drying and hydration lengths were found for fructose and glucose except for no hydration when flowers were kept dry for different times, flowers with 168 hours of drying had significantly more concentration of fructose and glucose (Figure 24-b and 24-c).



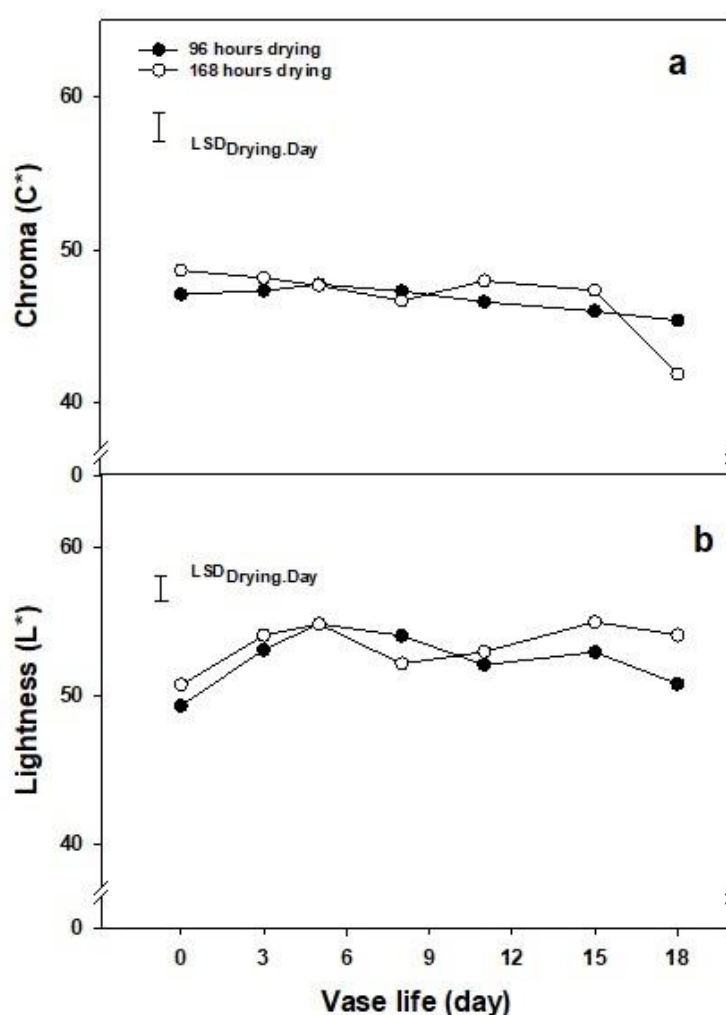
**Figure 24. Individual sugar concentration on day 18 of the vase life.** On day 18, the concentration of sugars (a: sucrose, b: fructose and c: glucose) was measured in the petals of flowers with two different drying lengths (96 and 168 hours) which had different hydration lengths (0, 12, 24 and 48 hours) and were kept at 18°C for 18 days. Error bars represent the standard deviation. The interaction between drying time and hydration time was not significant, hence  $LSD_{0.05}$  is not shown.

#### **4.2.8 Objective colour**

Chroma indicates how vivid or vibrant the colour of the roses is. It was significantly different during the vase life when roses had the same hydration (24 hours) and different drying (96 and 168 hours) time. Although different drying lengths did not make significant differences, the interaction of day and drying was significant (Table 19-a). The drying length had no significant effect on the chroma of the roses' petals during vase life, except for the final day when flowers with 168 hours of drying had ca. 8% lower chroma (45.34 and 41.07 for 96 and 168 hours of drying, respectively) (Figure 25-a).

Lightness which shows the darkening of the petals' colour, significantly increased during the vase life. In addition, the interaction between day and drying length was also significant (Table 19-b). Only between days 15 and 18, two drying lengths had a significant difference in which petals of flowers with 168 hours of drying were darker than those with 96 hours, at 54.08 and 50.77, respectively, on day 18 (Figure 25-b).

The intensity of the roses' colour is known as hue angle ( $h^\circ$ ). In this study interaction of drying lengths and day on roses'  $h^\circ$  was insignificant that is why figure is not plotted., Drying lengths and different days solely had significant effects on  $h^\circ$ . (Table 19-c).



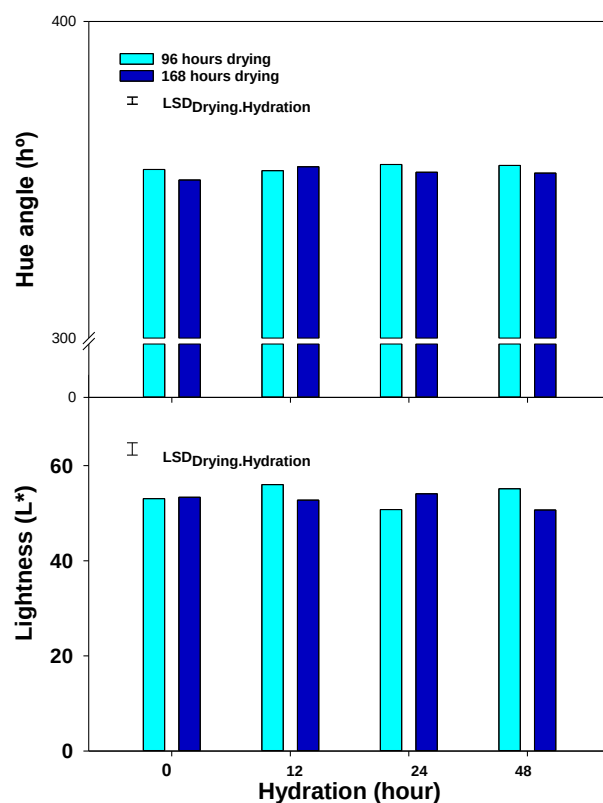
**Figure 25. Chroma (C\*) and lightness (L\*) of roses' petals during the vase life (day).** **a:** chroma (C\*) and **b:** lightness (L\*) were measured in the petals of flowers with two different drying lengths (96 and 168 hours) which both had 24 hours of hydration length and were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bar for interactions drying length x day has been shown where appropriate.

On day 18 of the vase life, longer drying time resulted in lower chroma, which was 43.70 for 168 hours of drying and 46.01 for 96 hours of drying. In addition, no significant difference was seen between hydration lengths and the interaction between drying and hydration was insignificant (Table 20-a).

Flowers with two drying lengths had significantly different lightness except for those with no hydration which 96 and 168 hours of drying resulted in the same lightness. On average, flowers with 96 hours of drying were ca. 10% lighter ( $L^*$ : 52.93) than those

with 168 hours of drying (48.33). Flowers that underwent 168 hours of drying and 48 hours of hydration exhibited the lowest level of lightness at 45.35 which was comparable to those subjected to 96 hours of drying and 24 hours of hydration. These two groups were significantly different from flowers that underwent 96 hours of drying and 12 hours of hydration (Figure 26-b).

Hue angle was significantly different between drying lengths (Table 20-c): a lower hue angle was seen in flowers with 168 hours of drying at 362.9, which was 361.15 for those with 96 hours of drying. Although varied hydrations could not make statistically meaningful differences, the interaction between hydration and drying was significant (figure 26-a). Flowers with 24 and 48 hours of drying had the highest  $h^\circ$  and flowers with 168 hours of drying and no hydration showed the lowest  $h^\circ$  at 358.95.



**Figure 26. Lightness ( $L^*$ ) and hue angle ( $h^\circ$ ) of roses' petals on the final day of the experiment.** a: hue angle ( $h^\circ$ ) and b: chroma ( $C^*$ ) were measured in the petals of flowers with two different drying lengths (96 and 168 hours) which had different hydration lengths (0, 12, 24 and 48 hours) and were kept at 18°C for 18 days. Least significant difference (LSD) ( $p < 0.05$ ) bars for the interactions drying length x hydration length have been shown where appropriate.

## 5 General discussion and conclusion

### 5.1 Discussion

In recent years, due to the popularity of online shopping and increasing in customer spending, the demand for fresh cut flowers has led to significant growth in the UK flower market. As ca. 90% of cut flowers are imported to the UK, keeping them dry in cold storage has been common; during the peak days (Valentine's and Mother's Days etc), retailers must import a higher number of flowers and they might store them under dry cold conditions for a longer time compared to the rest of the year.

Various research has been conducted to enhance flower longevity, primarily focusing on preservative solutions such as salicylic acid (Shabanian et al., 2019). Budiarto et al. (2022) investigated the effects of salicylic and ascorbic acid on extending the vase life of *chrysanthemum* cut flowers, with salicylic acid showing a slightly greater effect than ascorbic acid. It is reported that PIZFP, a specific protein found in herbaceous peony, facilitates the interactions between abscisic acid, gibberellin, and ethylene, contributing to the regulation of flower senescence in cut *herbaceous peony* (Ji et al., 2023).

#### **5.1.1 Prolonged dry storage time increases bent necks and damaged flowers during rose vase life**

According to this study, prolonged dry storage time (more than two days) resulted in increased percentages of bent necks and damaged flowers (physical damage), which can be attributed to the water stress and decrease in water content in flower organs as the dry period extends. According to Lear et al. (2022) the relationship between peduncle and bent neck in *Rosa hybrida* involves physiological and molecular mechanisms that contribute to reduced vase life and floral quality, with peduncle bending initiating the stress response and metabolic changes that lead to bent neck formation.

It is known that there is a sharp drop in water uptake and fresh weight of the flowers prior to neck bending (Van Meeteren, 1978); the reasons can be the gradual deterioration of the water transporting system by the accumulation of stem latex in the xylem after cutting the stems (Burdett, 2022) or xylem blockage by bacterial contamination (Bleeksma & Van Doorn, 2003). In addition, lack of water, senescence and carbohydrate loss can intensify the physical damage of cut flowers (Tripathi & Tuteja, 2007). As a result, preventing xylem blockage by applying preservative

solutions and choosing cultivars of flowers that release less latex (Burdett, 2022) when they are cut may lead to a longer vase life.

In this study, bent necks in 'Golden Smile' flowers started later than 'Revival Sweet', but on the final days of the experiment they showed a higher percentage of bent necks compared to 'Revival Sweet'. This can be attributed to the fact that 'Golden Smile' had stronger peduncles compared to 'Revival Sweet'. However, increased deterioration in water transportation following prolonged dry storage may result in higher percentages of physical damage and bent necks in this cultivar. As described by Burdett (2022), flowers' necks bend when the peduncle's constant water supply is limited; in fact, xylem blockage prevents water uptake and leads to bent necks (Bleeksma & Van Doorn, 2003). According to Zamski et al. (1991), cultivars with strong peduncles had a longer vase life and were more resistant to bent necks. Additionally, closed rings of vascular bundles offer greater resistance to bending than single ones do (Zamski et al., 1991), 'Golden Smile' may have closed ring which requires to be examined in the future works.

### ***5.1.2 Hydration solutions can increase the resistance of flowers to physical damage***

Using the hydration solution (Chrysal RVB) for more than 12 hours decreased the percentages of physical damage and bent necks significantly, which can result in lower water stress.

Acidic solutions can improve solution uptake, decrease vascular embolism, and prevent microbial growth, and, as a result, extend flower vase life. Chrysal RVB contains aluminium sulphate ( $\text{Al}_2\text{SO}_4$ ), which is known for reducing the pH and acidifying the preservative solutions (Liao et al., 2001). This biocidal nature of the aluminium sulphate can be considered as a beneficial effect on delaying the senescence of leaves and petals, hence improving vase life (Liao et al., 2001). Moreover, aluminium sulphate coagulates organic matter in water, prevents vascular plugging and improves solution uptake (Spricigo et al., 2021).

Aluminium sulphate forms  $\text{Al}(\text{OH})_3$  precipitate on the stems' surface, and it acts like a filter to capture bacteria and prevent xylem blockage (Liao et al., 2001) which can expand vase life. Additionally, it is observed that aluminium sulphate helps in reducing

water loss from cut flowers' transpiration by partially closing the stomata (Jamil et al., 2016).

Sharma and Bala, (2020) investigated how different composition of the flower food solution affected their pH and observed that the combination of sucrose and aluminium sulphate at 300 mg/L reduced pH from 7.6 to 4.73 resulting in a low pH and preventing microbial growth. In this study, it is observed that flowers with 168 hours of dry storage time with 48 hours of hydration can have a longer vase life than flowers with 96 hours of drying but less than 24 hours of hydration. Thus, keeping flowers in a hydration solution can eliminate the negative effects of prolonged dry storage. According to this study, when flowers have had prolonged dry storage, keeping them in the hydration solution for more than 24 hours can be suggested.

### ***5.1.3 Higher daily solution uptake demonstrates longer vase life***

The rate of solution uptake and transpiration determines vase life (Van Meeteren et al., 2015). Likewise, decreased water potential and low transpiration flow can cause the stem to lose turgidity due to vascular blockage (de Witte et al., 2014).

In this study, cumulative solution uptake increased over time. Flowers experiencing longer dry storage time uptake more water in the first few days due to the stem's dryness. However, as time went on, their solution uptake decreased because of a decline in stem's durability, and on the final days, the increase in cumulative solution uptake was slight. In other words, daily solution uptake declined by the end of the experiment due to the ending vase life, which can be due to air embolism in the stems, microbial proliferation, and plant response to wounding (Tilahun et al., 2016) and stem damage caused by fungi (figure 27).



**Figure 27. Stem damage on 'Revival Sweet' Roses.** Stem rottenness (red box) caused by *Botrytis cinerea* Pers had stopped solution uptake and led to wilting and bent necks (yellow box) (photo by Sara Hosseini). A close zoom of *Botrytis cinerea* Pers infection is shown on the right.

In addition, prolonged hydration solution usage (more than 24 hours) could increase daily and cumulative solution uptake as it facilitated solution uptake and helped flowers to keep up taking water.

Our results found that daily solution uptake is more important in vase life and higher daily solution uptake means longer vase life. Overall, it can be said that longer dry storage leads to more cumulative solution uptake due to the flower's dryness, and lower daily solution uptake can indicate a shorter vase life. It can be concluded that flowers with longer dry storage time had more cumulative solution uptake, but it does not mean they have a longer vase life. Previous research reported that higher solution uptake results in a longer vase life (D. Durkin, 2019; van Meeteren et al., 2006), this research can make this statement more specific to higher daily solution uptake results in longer vase life.

#### **5.1.4 *Roses flower opening could be slowed down by extending the hydration time***

An increase in bud diameter indicates that the flowers are opening. There is a correlation between the flowers' petal growth and flower opening, which is caused by cell expansion (Kenis et al., 1985). In this study, it was observed that rose buds grew as reached their maximum size, and then due to senescence and wilting, they became smaller indicating flower vase life is about to end. Whatever flowers open slower, the vase life might be longer as they get to the final stage of their life later. This shows the importance of flower opening management.

As Flowers with longer dry storage and shorter hydration lengths passed this stage quicker and it confirms they had the shortest vase life. As it is proved that flower opening or increase in bud diameter is limited by a decline in water potential (Van Meeteren et al., 1999), it can be concluded that longer hydration time decelerates the opening process and expands the vase life.

Van Doorn & de Witte (1991a) reported that cut roses opening depends on the carbohydrate content of the petals. Whilst Khan et al. (2015) investigated the effects of different preservative solutions on cut 'Red Pearl' roses. Sugar plays an important role in flower opening and having a longer vase life, as preservative solutions with higher concentration of sugar resulted in bigger bud diameter and a longer vase life.

Norikoshi et al. (2016) confirmed that sucrose increased cell expansion and moved petals significantly outwards, however, proper flower opening does not guarantee a long vase life. As Knee (2000) stated sugar encourages the proliferation of microorganisms that eventually clog the vessels of the xylem which confirms the importance of germicide usage. Chamani et al. (2005) linked both abnormal opening and suppression of flower opening to a shorter vase life. In fact, if flowers open quickly, they get to the final stage of their vase life in a shorter time and those flowers that do not open before ending their lives cause customer dissatisfaction.

#### **5.1.5 *Sugar concentration impacted vase life of roses***

The experiment demonstrates the relationship between solution uptake and sugar content. Our findings indicate that flowers with longer hydration times have higher concentrations of sucrose, glucose, and fructose (Figure 24), as well as higher levels of solution uptake and vase life. As the holding solution (flower food) contained sugars,

flowers with a higher amount of solution uptake had more sugar content on the final day of the experiment. In addition, flowers with prolonged dry storage time had significantly lower concentrations of sucrose in their petals.

In the rose petals, fructose concentration was approximately two and three times more than that of glucose and sucrose, respectively. As time went on, the sugar content in the petals decreased; this might be due to a drop in daily solution uptake which might be caused by senescence and xylem blockage. However, this could only be validated by carrying out further research including histology studies.

Sugar is known to provide a supply of nutrients that allows many cut flowers to last longer because they nourish tissues that need carbohydrates (Halevy & Mayak, 2011). Furthermore, sugars provide the primary substance for respiration, and sucrose is the most transformable form of sugar in cut flowers. As a result, commercially provided sucrose improves cut flower vase life by controlling the respiration rate, protecting the cell wall (O'Donoghue et al., 2002), and preserving petal colour (Bosma & Dole, 2002).

According to Knee (2000), sugar promotes the growth of microorganisms that ultimately clog xylems. Using sugar in conjunction with a germicide, such as aluminium sulphate, reduces microbial obstruction and lengthens the vase life of cut flowers. According to van Doorn & de Witte (1991), the amount of carbohydrates in the petals affects how soon cut roses open. Moreover, Norikoshi et al. (2016) confirmed that sucrose induced a substantial outward bend in the petals and boosted cell proliferation, however, a lengthy flower life is not assured by a good flower opening.

#### **5.1.6 Prolonged dry storage and hydration did not have considerable effects on colour**

According to colour examination on day 18 of the vase life, hue angle ( $h^\circ$ ) and lightness ( $L^*$ ) values varied slightly between drying and hydration lengths. As flowers with longer hydration lengths had more solution uptake and the holding solution (Moonpig) contained sugar, it was supposed that these flowers maintained their colour for longer and had higher chroma or more vivid colour. Nowak & Rudnicki (1990) found a positive correlation between petal colour and the availability of carbohydrates. The data suggested that there may be no discernible impact of the drying and hydration lengths on the colour, given the absence of a clear trend in the results.

On the other hand, examination of flowers with the same hydration time (24 hours) and different drying lengths (96 and 168 hours) over time showed flowers' colour became duller as their chroma decreased. According to Hettiarachchi & Balas (2010), this can be because of senescence. They investigated the effect of cold dry storage on Gloriosa (*Gloriosa superba*. L). According to their findings, chroma can drop due to senescence, which is in accordance with this study. Additionally, they noticed that the Hue angle increased during that time which controvert with this study's result.

In general, it can be said that drying did not have considerable effects on the 'Revival Sweet' colour which might be because of the pink colour of the petals. According to Misra et al. (2003), flowers of the *chrysanthemum* plant that are pink or yellow maintain their colour after being dehydrated, whereas flowers that are white to reddish-white, red, blue, and darker undergo a significant lightness. Since the objective colour flower petals depends on the concentration and ratio of different pigments, and colour changes are affected by senescence processes, future experiments including flowers with different colours can test this hypothesis that the yellow colour of 'Golden Smile' was the reason for not seeing significant differences in the current experiment.

#### **5.1.7 Challenges of the project and suggestions for improvement in future works**

We faced some problems with the pictures on day 18 when the flowers' necks were bent, or we had fungal contamination on the petals (Figure 28). For future experiments, it would be a clever idea to put the buds straight for bud measurement then remove petals from various parts of the buds for colour measurement and check if there are any differences with when colour is measured on the whole bud.



**Figure 28. Example of a picture that was difficult to obtain RGB in.** Because there are three buds with bent necks it was impossible to see the whole cross-section of the buds. In addition, the brown colour resulting from *Botrytis cinerea* can affect the results negatively (photo by Sara Hosseini).

In this study, we did not have the data for vase water pH and aerobic colony counts, flower opening, and petal sugar concentration during the vase life for different hydrations. However, we measured the physical damages and solution uptake during the whole experiment and could discuss the results properly. It can be suggested for future experiments, to have a look at changes in these variations to examine the exact effects of various hydrations during the whole vase life.

## 5.2 Conclusion

Global trade in cut flowers has been increasing, and *approximately* 90% of them are imported to the UK (Statista, 2022), to regulate supply chain and market demand cold dry storage has become frequent (Nguyen et al., 2020; Skutnik et al., 2020). But the problem is that with prolonged dry storage cut flower vase life would be shortened.

This study examined the effects of dry storage on vase life, as well as the potential to eliminate the negative impacts of dry storage by expanding the time of hydration.

Investigation of prolonged dry storage time can confirm that 'Golden Smile' and 'Revival Sweet' flowers with shorter drying lengths tend to have a longer vase life. Additionally, it can be confirmed that 'Revival Sweet' has a longer vase life than 'Golden Smile'. As a key achievement of this study, when 'Revival Sweet' flowers have been kept dry in cold storage for more than 4 days, expanding the hydration time to more than 24 hours can be considered to significantly expand their vase life. As expanding the hydration length proved beneficial, it could increase solution uptake and delay senescence, resulting in an improved vase life. Interestingly, a longer hydration time allowed flowers to manifest symptoms of physical damage at a later stage.

'Golden Smile' has a problem with flower opening resulting in customer complaints. While this cultivar has a stronger peduncle and on the first 12 days of the experiment, they were more resistant to the bent necks. Still, they showed a high percentage of bent necks and physical damage on the final days of the experiment which may be because of deterioration in their water transportation system. In addition, this cultivar.

Overall, this study has been conducted to address the problem that Arena Flowers Company had during the peak days. Flowers are kept dry in cold dry storage for a longer time than normal days of the year, this negatively affects flower longevity or vase life and can lead to customer dissatisfaction. According to the results of this project, expanding the hydration time from 24 to 48 hours can significantly eliminate the negative effects of prolonged dry storage time and increase longevity.

### **5.3 Recommendations for future experimental work**

A comprehensive strategy that includes a range of experimental approaches is advised in the quest to increase the vase life of cut flowers:

#### ***5.3.1 Investigation of the impact of individual sugar concentration on vase life***

As sugar has a key role in flower vase life (Jani & Mankad, 2013; Pun & Ichimura, 2003), it is important to understand the effects of different concentrations of individual sugar. In addition, flower suppliers are using commercially provided preservative solutions containing sugar before sending flowers to the final customers and sending some sachets of flower food to customers. Knowing the optimal time and concentration of these solutions can help retailers gain more customer satisfaction and may save resources.

This future study will employ commercially available solutions to examine the relationship between sugar concentrations and the length of use as a pulsing solution on the vase life. The experimental design should facilitate a comprehensive understanding of the optimal sugar concentrations contributing to prolonged vase life.

#### ***5.3.2 Examination of packaging strategies on the vase life of cut flowers***

To investigate the effects of different packaging on the vase life of cut flowers, the same materials and methods will be used to pack the flowers while importing flowers from farms to the UK and from retailers to final customer delivery. This study will work on considering air circulation and ethylene concentration and focus on crucial factors such as moisture retention, ethylene concentration and microbial growth prevention. This will try to refine packaging practices to maximize the preservation of cut flower quality.

#### ***5.3.3 Determination of vase life in mixed bouquets***

These days flowers are sold in mixed bouquets (Kenanoğlu, 2023). Identifying the effects of different flowers can be a practical idea for delving into the dynamic interactions between them. This study will seek to observe their collective influence on each other's longevity by carefully orchestrating arrangements with varied floral components. It will aim to glean insights into the harmonious or conflicting relationships within mixed bouquets, ultimately enhancing the overall longevity of these curated floral ensembles.

#### **5.3.4 Identification of the optimal storage condition**

To explore the impact of diverse storage conditions on the longevity of cut flowers, experiments will be done involving varying temperatures and humidity conditions. This study will aspire to uncover the conditions that foster extended vase life by scrutinizing factors such as Ethylene in the environment. It will contribute to a refined understanding of the delicate balance between storage temperature and humidity with flower longevity. The overall goal will be to gain a deeper understanding of the variables affecting the longevity of cut flowers by providing knowledge that may guide more effective preservation techniques in flower management.

#### **5.3.5 Study on sustainable cut flower production and waste management**

A comprehensive examination of the pesticides and fertilisers will be employed in the cultivation process to assess their potential environmental impact. This investigation will scrutinize the ecological consequences of pesticide and fertiliser usage, considering factors such as soil health, water quality, broader ecosystem integrity, and ultimately waste management. This research will aspire to inform conscientious and environmentally friendly practices within the cut flower industry, fostering a balance between floral cultivation, waste management and environmental preservation.

A high proportion of pesticides is required in flower cultivation (Etheredge & Waliczek, 2022), and these pesticides are easily able to contaminate natural resources if their waste is left in nature. This experiment might find an ecofriendly way to dispose of cut flower wastes. Production of vermicompost can be examined to check if it is a proper way to destroy the remaining dangerous pesticides in a biological method.

## References

- Adhikari, B., & G.C., A. (2021). Post-harvest practices of horticultural crops in Nepal: Issues and management. *Archives of Agriculture and Environmental Science*, 6(2). <https://doi.org/10.26832/24566632.2021.0602015>
- Ahsan, M., Ramzan, A., Nafees, M., Younis, A., Amin, M., Akhtar, G., Saleem, K., & Sabeeh, A. (2021). Comparative Study of Different Preservative Solutions for Extending Flower Quality and Market Acceptability of Rosa hybrida Cv. Freedom. *Pakistan Journal of Agricultural Research*, 34(3). <https://doi.org/10.17582/JOURNAL.PJAR/2021/34.3.545.551>
- Altman, A., Shennan, S., & Odling-Smee, J. (2022). Ornamental plant domestication by aesthetics-driven human cultural niche construction. In *Trends in Plant Science* (Vol. 27, Issue 2). <https://doi.org/10.1016/j.tplants.2021.09.004>
- Asrar, A. W. A. (2012a). Effects of some preservative solutions on vase life and keeping quality of snapdragon (*Antirrhinum majus* L.) cut flowers. *Journal of the Saudi Society of Agricultural Sciences*, 11(1). <https://doi.org/10.1016/j.jssas.2011.06.002>
- Asrar, A. W. A. (2012b). Effects of some preservative solutions on vase life and keeping quality of snapdragon (*Antirrhinum majus* L.) cut flowers. *Journal of the Saudi Society of Agricultural Sciences*, 11(1), 29–35. <https://doi.org/10.1016/J.JSSAS.2011.06.002>
- Babalola, A. O., Sundarakani, B., & Ganesh, K. (2011). Cold chain logistics in the floral industry. *International Journal of Enterprise Network Management*, 4(4). <https://doi.org/10.1504/IJENM.2011.043801>
- Bleeksma, H. C., & Van Doorn, W. G. (2003). Embolism in rose stems as a result of vascular occlusion by bacteria. *Postharvest Biology and Technology*, 29(3). [https://doi.org/10.1016/S0925-5214\(03\)00049-8](https://doi.org/10.1016/S0925-5214(03)00049-8)
- Bosma, T., & Dole, J. M. (2002). Postharvest handling of cut *Campanula medium* flowers. *HortScience*, 37(6). <https://doi.org/10.21273/hortsci.37.6.954>
- Bradley, C. G., & Corsini, L. (2023). A literature review and analytical framework of the sustainability of reusable packaging. In *Sustainable Production and Consumption* (Vol. 37). <https://doi.org/10.1016/j.spc.2023.02.009>
- Budiarto, K., Zamzami, L., & Endarto, O. (2022). Effect of salicylic and ascorbic acids on post-harvest vase life of *Chrysanthemum* cut flowers. *Horticultural Science*, 49(1). <https://doi.org/10.17221/151/2020-HORTSCI>
- Burdett, A. N. (2022). The Cause of Bent Neck in Cut Roses1. *Journal of the American Society for Horticultural Science*, 95(4), 427–431. <https://doi.org/10.21273/jashs.95.4.427>
- Çelikel, F. G., & Reid, M. S. (2002). Storage temperature affects the quality of cut flowers from the asteraceae. *HortScience*, 37(1). <https://doi.org/10.21273/hortsci.37.1.148>

- Çelikel, F. G., Reid, M. S., & Jiang, C. Z. (2020). Postharvest physiology of cut *Gardenia jasminoides* flowers. *Scientia Horticulturae*, 261. <https://doi.org/10.1016/j.scienta.2019.108983>
- Chalumuru, G. K., Nair, S. A., & Srinivas, M. (2014). Effect of precooling and chemical preservatives on post harvest longevity of tuberose ( *Polianthes tuberosa* L. ) florets . *International Journal of Agriculture, Environment and Biotechnology*, 8(1). <https://doi.org/10.5958/2230-732x.2015.00008.x>
- Chamani, E., Khalighi, A., Joyce, D. C., Irving, D. E., Zamani, Z. A., Mostofia, Y., & Kafi, M. (2005). Ethylene and anti-ethylene treatment effects on cut “First Red” rose. *Journal of Applied Horticulture*, 07(01). <https://doi.org/10.37855/jah.2005.v07i01.01>
- Clark, E. M. R., Dole, J. M., Carlson, A. S., Moody, E. P., McCall, I. F., Fanelli, F. L., & Fonteno, W. C. (2010). Vase life of new cut flower cultivars. *HortTechnology*, 20(6). <https://doi.org/10.21273/hortsci.20.6.1016>
- Costa, L. C., Costa, R. R., Ribeiro, W. S., Carneiro, G. G., Barbosa, J. A., & Finger, F. L. (2015). Postharvest longevity of *Heliconia wagneriana*. *Acta Horticulturae*, 1060. <https://doi.org/10.17660/ActaHortic.2015.1060.28>
- da Costa, L. C., & Finger, F. L. (2016). Flower opening and vase life of gladiolus cultivars: The sensitivity to ethylene and the carbohydrate content. *Ornamental Horticulture*, 22(2). <https://doi.org/10.14295/oh.v22i2.901>
- Damalas, C. A., & Eleftherohorinos, I. G. (2011). Pesticide exposure, safety issues, and risk assessment indicators. In *International Journal of Environmental Research and Public Health* (Vol. 8, Issue 5). <https://doi.org/10.3390/ijerph8051402>
- Darras, A. I. (2020). The chilling injury effect in cut flowers: a brief review. In *Journal of Horticultural Science and Biotechnology* (Vol. 95, Issue 1). <https://doi.org/10.1080/14620316.2019.1629340>
- de Witte, Y., Harkema, H., & Van Doorn, W. G. (2014). Effect of antimicrobial compounds on cut Gerbera flowers: Poor relation between stem bending and numbers of bacteria in the vase water. *Postharvest Biology and Technology*, 91. <https://doi.org/10.1016/j.postharvbio.2013.12.018>
- De Witte, Y., & Van Doorn, W. G. (1988). Identification of bacteria in the vase water of roses, and the effect of the isolated strains on water uptake. *Scientia Horticulturae*, 35(3–4), 285–291. [https://doi.org/10.1016/0304-4238\(88\)90122-7](https://doi.org/10.1016/0304-4238(88)90122-7)
- Dean, R., Van Kan, J. A. L., Pretorius, Z. A., Hammond-Kosack, K. E., Di Pietro, A., Spanu, P. D., Rudd, J. J., Dickman, M., Kahmann, R., Ellis, J., Ellis, J., & Foster, G. D. (2012). The Top 10 fungal pathogens in molecular plant pathology. *Molecular Plant Pathology*, 13(7), 804–804. <https://doi.org/10.1111/j.1364-3703.2012.00822.x>
- Doublet, V., Doyle, T., Refoy, I., Hedges, S., Carvell, C., Brown, M. J. F., & Wilfert, L. (2022). Increasing flower species richness in agricultural landscapes alters insect pollinator networks: Implications for bee health and competition. *Ecology and Evolution*, 12(10). <https://doi.org/10.1002/ece3.9442>

- Durkin, D. (2019). PRE-STORAGE HYDRATING SOLUTION EFFECTS ON FLOWER LIFE OF ROSES AFTER DRY STORAGE. *HortScience*, 27(6). <https://doi.org/10.21273/hortsci.27.6.616d>
- Durkin, D. J. (2022). Some Characteristics of Water Flow through Isolated Rose Stem Segments1. *Journal of the American Society for Horticultural Science*, 104(6). <https://doi.org/10.21273/jashs.104.6.777>
- Elgimabi, M. E. N. E. (2011). Vase life extension of rose cut flowers (*rosa hybrida*) as influenced by silver nitrate and sucrose pulsing. *American Journal of Agricultural and Biological Science*, 6(1). <https://doi.org/10.3844/ajabssp.2011.128.133>
- Elhindi, K. M. (2012). Effects of postharvest pretreatments and preservative solutions on vase life longevity and flower quality of sweet pea (*Lathyrus odoratus* L.). *Photosynthetica*, 50(3). <https://doi.org/10.1007/s11099-012-0053-3>
- Etheredge, C. L., & Waliczek, T. M. (2022). An Analysis of the Quality of Compost Produced from Vermicomposting Fresh Cut Flower Waste. *Journal of Environmental Horticulture*, 40(2). <https://doi.org/10.24266/2573-5586-40.2.87>
- Fatima, K., Ahmad, I., Dole, J. M., Ahmad, N., Asif, M., Ziaf, K., Badar, M. A., & Fatima, K. (2022). Folk floral preservatives extend postharvest longevity of *Eustoma grandiflorum* L. *Scientia Horticulturae*, 301. <https://doi.org/10.1016/j.scienta.2022.111132>
- Gómez-Merino, F. C., Castillo-González, A. M., Ramírez-Martínez, M., & Trejo-Téllez, L. I. (2020). Lanthanum delays senescence and improves postharvest quality in cut tulip (*Tulipa gesneriana* L.) flowers. *Scientific Reports*, 10(1). <https://doi.org/10.1038/s41598-020-76266-0>
- Gul, F., Tahir, I., & Shahri, W. (2020). Flower senescence and some postharvest considerations of *Amaryllis belladonna* cut scapes. *Plant Physiology Reports*, 25(2). <https://doi.org/10.1007/s40502-020-00506-8>
- Gupta, J., & Dubey, R. K. (2018). Factors Affecting Post-Harvest Life of Flower Crops. *International Journal of Current Microbiology and Applied Sciences*, 7(1). <https://doi.org/10.20546/ijcmas.2018.701.065>
- Ha, S. T. T., Kim, Y. T., Jeon, Y. H., Choi, H. W., & In, B. C. (2021). Regulation of *botrytis cinerea* infection and gene expression in cut roses by using nano silver and salicylic acid. *Plants*, 10(6). <https://doi.org/10.3390/plants10061241>
- Halevy, A. H., & Mayak, S. (2011). Senescence and Postharvest Physiology of Cut Flowers-Part 2. In *Horticultural Reviews*. <https://doi.org/10.1002/9781118060766.ch3>
- Harford, T. (2019). *How to solve the plastic packaging paradox*. BBC News.
- Hettiarachchi, M. P., & Balas, J. (2010). Effects of cold storage on post harvest keeping quality of Gloriosa (*Gloriosa superba* L.) flowering stems. *Tropical Agricultural Research and Extension*, 7(0). <https://doi.org/10.4038/tare.v7i0.5422>

- Ichimura, K., & Goto, R. (2002). Extension of vase life of cut *Narcissus tazetta* var. *chinensis* flowers by combined treatment with STS and gibberellin A3. *Journal of the Japanese Society for Horticultural Science*, 71(2). <https://doi.org/10.2503/jjshs.71.226>
- Jamil, M., Rahman, M., Hossain, M., Hossain, M., & Karim, A. S. (2016). Influence of sucrose and aluminium sulphate vase life of cut *Hippeastrum* flower (*Hippeastrum hybridum* Hort.) as influenced. *Bangladesh Journal of Agricultural Research*, 41(2). <https://doi.org/10.3329/bjar.v41i2.28217>
- Jani, G., & Mankad, A. (2013). Changes in sugars during petal senescence in cut flowers of *Cosmos bipinnatus*. *Phytomorphology: An International Journal of Plant Morphology*, 63(3–4).
- Jawaharlal, M., Thamaraiselvi, S. P., & Ganga, M. (2012). Packaging Technology for Export of Jasmine (*Jasminum sambac* Ait.) Flowers. *Journal of Horticultural Sciences*, 7(2). <https://doi.org/10.24154/jhs.v7i2.372>
- Ji, X., Yuan, Y., Bai, Z., Wang, M., Niu, L., & Sun, D. (2023). PIZFP mediates the combinatorial interactions of abscisic acid with gibberellin and ethylene during flower senescence in cut herbaceous peony. *Postharvest Biology and Technology*, 195. <https://doi.org/10.1016/j.postharvbio.2022.112130>
- Jia, Z., Fernandes, M. C., Deng, Z., Yang, T., Zhang, Q., Lethbridge, A., Yin, J., Lee, J. H., Han, L., Weaver, J. C., Bertoldi, K., Aizenberg, J., Kolle, M., Vukusic, P., & Li, L. (2021). Microstructural design for mechanical-optical multifunctionality in the exoskeleton of the flower beetle *Torynorrhina flammea*. *Proceedings of the National Academy of Sciences of the United States of America*, 118(25). <https://doi.org/10.1073/pnas.2101017118>
- Jorgensen, R., & Arathi, H. S. (2013). Floral longevity and autonomous selfing are altered by pollination and water availability in *Collinsia heterophylla*. *Annals of Botany*, 112(5). <https://doi.org/10.1093/aob/mct146>
- Kaur, H., Gelain, J., Calidonio, J., Muñoz, M., Faust, J. E., & Schnabel, G. (2023). Efficacy of calcium propionate against fungicide-resistant fungal plant pathogens and suppression of botrytis blight of ornamental flowers. *Pesticide Biochemistry and Physiology*, 194. <https://doi.org/10.1016/j.pestbp.2023.105472>
- Kenanoğlu, Z. (2023). Marketing Channel Preferences of Cut Flower Producers: A Case Study of Turkey. *Horticulturae*, 9(3). <https://doi.org/10.3390/horticulturae9030372>
- Kenis, J. D., Silvente, S. T., & Trippi, V. S. (1985). Nitrogen metabolism and senescence-associated changes during growth of carnation flowers. *Physiologia Plantarum*, 65(4). <https://doi.org/10.1111/j.1399-3054.1985.tb08673.x>
- Khan, P., Shahrin, S., Taufique, T., Mehraj, H., & Jamal Uddin, A. F. M. (2015). Prolonging vase life of cut rose (*Rosa hybrida* L. cv. Red Pearl) through chemical preservatives. *Journal of Bioscience and Agriculture Research*, 5(1). <https://doi.org/10.18801/jbar.050115.49>

- Khunmuang, S., Kanlayanarat, S., Wongs-Aree, C., Meir, S., Philosoph-Hadas, S., Oren-Shamir, M., Ovadia, R., & Buanong, M. (2019). Ethylene Induces a Rapid Degradation of Petal Anthocyanins in Cut Vanda 'Sansai Blue' Orchid Flowers. *Frontiers in Plant Science*, 10. <https://doi.org/10.3389/fpls.2019.01004>
- Klatt, B. K., Burmeister, C., Westphal, C., Tschardtke, T., & von Fragstein, M. (2013). Flower Volatiles, Crop Varieties and Bee Responses. *PLoS ONE*, 8(8). <https://doi.org/10.1371/journal.pone.0072724>
- Knee, M. (2000). Selection of biocides for use in floral preservatives. *Postharvest Biology and Technology*, 18(3). [https://doi.org/10.1016/S0925-5214\(99\)00074-5](https://doi.org/10.1016/S0925-5214(99)00074-5)
- Kumar, A., Gandhi, N., & Tinna, D. (2019). Effect of different packaging material under different temperature conditions on physical properties and shelf life of rose (*Rosa indica*) and plumeria (*Plumeria alba*). *Journal of Pharmacognosy and Phytochemistry*, 8(Spec.Iss.1).
- Lan, Y. C., Tam, V. W., Xing, W., Rina Datt, & Chan, Z. (2022). Life cycle environmental impacts of cut flowers: A review. In *Journal of Cleaner Production* (Vol. 369). <https://doi.org/10.1016/j.jclepro.2022.133415>
- Lear, B., Casey, M., Stead, A. D., & Rogers, H. J. (2022). Peduncle Necking in *Rosa hybrida* Induces Stress-Related Transcription Factors, Upregulates Galactose Metabolism, and Downregulates Phenylpropanoid Biosynthesis Genes. *Frontiers in Plant Science*, 13. <https://doi.org/10.3389/fpls.2022.874590>
- Leon, J., Pavon, M., Murillo, D., Leon, M., Guatumillo, D., & Toroshina, J. (2023). Waste managing plan for floriculture plants. *Minerva*, 4(11). <https://doi.org/10.47460/minerva.v4i11.126>
- Leonard, R. T., Alexander, A. M., & Nell, T. A. (2011). Postharvest performance of selected Colombian cut flowers after three transport systems to the United States. *HortTechnology*, 21(4). <https://doi.org/10.21273/horttech.21.4.435>
- Li, Z., McCracken, V., & Connolly, J. (2016). An evaluation of factors influencing consumer purchase decisions of cut flowers: A study of Washington consumers. *Agricultural & Applied Economics Association Annual Meeting*.
- Liao, L. J., Li, Y. H., Huang, K. L., & Chen, W. S. (2001). Vase life of *Eustoma grandiflorum* as affected by aluminum sulfate. *Botanical Bulletin of Academia Sinica*, 42(1).
- Loubaud, M., & Van Doorn, W. G. (2004). Wound-induced and bacteria-induced xylem blockage in roses, *Astilbe*, and *Viburnum*. *Postharvest Biology and Technology*, 32(3). <https://doi.org/10.1016/j.postharvbio.2003.12.004>
- Loyola, C. E., Dole, J. M., & Dunning, R. (2019). South and central america cut flower production and postharvest survey. *HortTechnology*, 29(6). <https://doi.org/10.21273/HORTTECH04484-19>
- Macnish, A. J., De Theije, A., Reid, M. S., & Jiang, C. Z. (2009). An alternative postharvest handling strategy for cut flowers - Dry handling after harvest. *Acta Horticulturae*, 847. <https://doi.org/10.17660/ActaHortic.2009.847.27>

- Manikas, I., Malindretos, G., & Abeliotis, K. (2020). Sustainable Cities through Alternative Urban Farming: The Case of Floriculture. *Journal of International Food and Agribusiness Marketing*, 32(3). <https://doi.org/10.1080/08974438.2019.1599762>
- Maree, J., & van Wyk, B.-E. (2020). Cut Flowers of the World. In *Cut Flowers of the World*. <https://doi.org/10.1079/9781789241334.0000>
- Menegaes, J. F., Nunes, U. R., Backes, F. A. A. L., Swarowsky, A., Fiorin, T. T., & de Lima Franzen, F. (2023a). Post-harvest quality of safflower flower stems with different pre-cooling periods and preservative solutions. *Comunicata Scientiae*, 14. <https://doi.org/10.14295/CS.v14.3923>
- Menegaes, J. F., Nunes, U. R., Backes, F. A. A. L., Swarowsky, A., Fiorin, T. T., & de Lima Franzen, F. (2023b). Post-harvest quality of safflower flower stems with different pre-cooling periods and preservative solutions. *Comunicata Scientiae*, 14. <https://doi.org/10.14295/CS.v14.3923>
- Menegaes, J. F., Nunes, U. R., Bellé, R. A., & Backes, F. A. A. L. (2019). Post-harvesting of cut flowers and ornamental plants. *Scientia Agraria Paranaensis*. <https://doi.org/10.18188/sap.v18i4.21261>
- Mengistie, B. T., Mol, A. P. J., & Oosterveer, P. (2017). Governance of agro-pesticide through private environmental and social standards in the global cut flower chain from Ethiopia. *Ambio*, 46(7). <https://doi.org/10.1007/s13280-017-0914-x>
- Misra, P., Datta, S. K., & Chakrabarty, D. (2003). Mutation in flower colour and shape of *Chrysanthemum morifolium* induced by  $\gamma$ -radiation. *Biologia Plantarum*, 47(1). <https://doi.org/10.1023/A:1027365822769>
- Mochizuki, J., Itagaki, T., Aoyagi Blue, Y., Ito, M., & Sakai, S. (2019). Ovule and seed production patterns in relation to flower size variations in actinomorphic and zygomorphic flower species. *AoB PLANTS*, 11(5). <https://doi.org/10.1093/aobpla/plz061>
- Mortensen, L. M., & Gislerød, H. R. (1999). Influence of air humidity and lighting period on growth, vase life and water relations of 14 rose cultivars. *Scientia Horticulturae*, 82(3–4). [https://doi.org/10.1016/S0304-4238\(99\)00062-X](https://doi.org/10.1016/S0304-4238(99)00062-X)
- Muñoz, M., Faust, J. E., & Schnabel, G. (2019). Characterization of *Botrytis cinerea* from commercial cut flower roses. *Plant Disease*, 103(7). <https://doi.org/10.1094/PDIS-09-18-1623-RE>
- Natarella, N. J., & Kays, S. J. (2022). Effect of Storage Temperature on Cut Flowers of *Ranunculus asiaticus* L.1. *HortScience*, 14(4). <https://doi.org/10.21273/hortsci.14.4.504>
- Nguyen, T. K., Jung, Y. O., & Lim, J. H. (2020). Tools for Cut Flower for Export: Is It a Genuine Challenge from Growers to Customers? *Flower Research Journal*, 28(4). <https://doi.org/10.11623/frj.2020.28.4.02>
- Nijse, J., Van Meeteren, U., & Keijzer, C. J. (2000). Air in xylem vessels of cut flowers. *Acta Horticulturae*, 517. <https://doi.org/10.17660/ActaHortic.2000.517.61>

- Norikoshi, R., Shibata, T., Niki, T., & Ichimura, K. (2016). Sucrose treatment enlarges petal cell size and increases vacuolar sugar concentrations in cut rose flowers. *Postharvest Biology and Technology*, 116. <https://doi.org/10.1016/j.postharvbio.2016.01.003>
- Norman, D. J., & Ali, G. S. (2012). Anthurium Diseases: Identification and Control in Commercial Greenhouse Operations. *EDIS*, 2012(4). <https://doi.org/10.32473/edis-pp292-2012>
- Nowak, J., & Rudnicki, R. M. (1990). Postharvest Handling and Storage of Cut Flowers, Florist Greens, and Potted Plants. In *Postharvest Handling and Storage of Cut Flowers, Florist Greens, and Potted Plants*. <https://doi.org/10.1007/978-94-009-0425-5>
- Nyakutsikwa, B., Walsh, T., Pretty, I., & Moore, D. (2022). Water fluoride concentrations in England, 2009-2020. *Community Dental Health*, 39(2). [https://doi.org/10.1922/CDH\\_00267Nyakutsikwa07](https://doi.org/10.1922/CDH_00267Nyakutsikwa07)
- O'Donoghue, E. M., Somerfield, S. D., & Heyes, J. A. (2002). Vase solutions containing sucrose result in changes to cell walls of sandersonia (*Sandersonia aurantiaca*) flowers. *Postharvest Biology and Technology*, 26(3). [https://doi.org/10.1016/S0925-5214\(02\)00045-5](https://doi.org/10.1016/S0925-5214(02)00045-5)
- Ou, S. H. (1980). Pathogen Variability and Host Resistance in Rice Blast Disease. *Annual Review of Phytopathology*, 18(1). <https://doi.org/10.1146/annurev.py.18.090180.001123>
- Öztürk, A., & Bastas, K. K. (2022). Effects of climate changes on rose fungal and bacterial diseases in lands-cape areas of Konya province, Türkiye. *Selcuk Journal of Agricultural and Food Sciences*. <https://doi.org/10.15316/SJAFS.2022.079>
- Peiró-Signes, A., Miret-Pastor, L., & Segarra-Oña, M. (2020). Effects of green certification and labelling on the Spanish fisheries industry. *Aquaculture Reports*, 17, 100396. <https://doi.org/10.1016/J.AQREP.2020.100396>
- Pun, U. K., & Ichimura, K. (2003). Role of Sugars in Senescence and Biosynthesis of Ethylene in Cut Flowers. In *Japan Agricultural Research Quarterly* (Vol. 37, Issue 4). <https://doi.org/10.6090/jarq.37.219>
- Rabiza-Świder, J., Rochala, J., Jedrzejuk, A., Skutnik, E., & Łukaszewska, A. (2016). Symptoms of programmed cell death in intact and cut flowers of clematis and the effect of a standard preservative on petal senescence in two cultivars differing in flower longevity. *Postharvest Biology and Technology*, 118, 183–192. <https://doi.org/10.1016/J.POSTHARVBIO.2016.04.008>
- Regan, E. M., & Dole, J. M. (2010). Determining optimum ph and ec levels for extended vase life of cut rosa Freedom Charlotte and Classy. *Acta Horticulturae*, 870. <https://doi.org/10.17660/ActaHortic.2010.870.35>
- Reid, M. S. (2016). Cut flowers and greens. In *The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks*.
- Reid, M. S., & Jiang, C. Z. (2005). New strategies in transportation for floricultural crops. *Acta Horticulturae*, 682. <https://doi.org/10.17660/ActaHortic.2005.682.222>

- Rihn, A. L., Yue, C., Hall, C., & Behe, B. K. (2014). Consumer preferences for longevity information and guarantees on cut flower arrangements. *HortScience*, 49(6). <https://doi.org/10.21273/hortsci.49.6.769>
- Rogers, H. J. (2006). Programmed cell death in floral organs: How and why do flowers die? In *Annals of Botany* (Vol. 97, Issue 3). <https://doi.org/10.1093/aob/mcj051>
- Rudnicki, R. M., Nowak, J., & Goszczynska, D. M. (1991). COLD STORAGE AND TRANSPORTATION CONDITIONS FOR CUT FLOWERS CUTTINGS AND POTTED PLANTS. *Acta Horticulturae*, 298. <https://doi.org/10.17660/actahortic.1991.298.27>
- Sahle, A., & Potting, J. (2013). Environmental life cycle assessment of Ethiopian rose cultivation. *Science of the Total Environment*, 443. <https://doi.org/10.1016/j.scitotenv.2012.10.048>
- Sarwat, M., & Tuteja, N. (2019). Flower Senescence: Present Status and Future Aspects. *Senescence Signalling and Control in Plants*, 211–225. <https://doi.org/10.1016/B978-0-12-813187-9.00013-5>
- Seaton, K. A., & Joyce, D. C. (1993). Effects of low temperature and elevated CO<sub>2</sub> treatments and of heat treatments for insect disinfestation on some native Australian cut flowers. *Scientia Horticulturae*, 56(2), 119–133. [https://doi.org/10.1016/0304-4238\(93\)90013-G](https://doi.org/10.1016/0304-4238(93)90013-G)
- Shabanian, S., Nasr Esfahani, M., Karamian, R., & Tran, L. S. P. (2019). Salicylic acid modulates cutting-induced physiological and biochemical responses to delay senescence in two gerbera cultivars. *Plant Growth Regulation*, 87(2). <https://doi.org/10.1007/s10725-018-0466-5>
- Sharma, N., & Bala, M. (2020). EFFECT OF DIFFERENT HOLDING SOLUTIONS ON POST-HARVEST KEEPING QUALITY OF CHRYSANTHEMUM CUT STEMS. *Agricultural Research Journal*, 57(3). <https://doi.org/10.5958/2395-146X.2020.00056.3>
- Sharma, P., & Thakur, N. (2020). Effect of pulsing and storage methods for extending vase life of cut flowers. *International Journal of Chemical Studies*, 8(6). <https://doi.org/10.22271/chemi.2020.v8.i6s.10943>
- Shewfelt, R. L., & Prussia, S. E. (2021). Postharvest handling: A systems approach. In *Postharvest Handling: A Systems Approach*. <https://doi.org/10.1016/C2009-0-03328-5>
- Singh, A. K., Asmita, Sisodia, A., Pal, A., & Barman, K. (2016). Effect of sucrose and aluminium sulphate on postharvest life of liliun cv. Monarch. *Journal of Hill Agriculture*, 7(2). <https://doi.org/10.5958/2230-7338.2016.00050.1>
- Skutnik, E., Rabiza-Swider, J., Jedrzejuk, A., & Łukaszewska, A. (2020). The effect of the long-term cold storage and preservatives on senescence of cut herbaceous peony flowers. *Agronomy*, 10(11). <https://doi.org/10.3390/agronomy10111631>
- Soode, E., Lampert, P., Weber-Blaschke, G., & Richter, K. (2015). Carbon footprints of the horticultural products strawberries, asparagus, roses and

- orchids in Germany. *Journal of Cleaner Production*, 87(1).  
<https://doi.org/10.1016/j.jclepro.2014.09.035>
- Spricigo, P. C., Pilon, L., Trento, J. P., de Moura, M. R., Bonfim, K. S., Mitsuyuki, M. C., Mattoso, L. H. C., & Ferreira, M. D. (2021). Nano-chitosan as an antimicrobial agent in preservative solutions for cut flowers. *Journal of Chemical Technology and Biotechnology*, 96(8).  
<https://doi.org/10.1002/jctb.6766>
- Staby, G. L., & Erwin, T. D. (2022). Water Quality, Preservative, Grower Source and Chrysanthemum Flower Vase-life1. *HortScience*, 13(2).  
<https://doi.org/10.21273/hortsci.13.2.185>
- Sun, J., Guo, H., & Tao, J. (2022). Effects of Harvest Stage, Storage, and Preservation Technology on Postharvest Ornamental Value of Cut Peony (*Paeonia lactiflora*) Flowers. *Agronomy*, 12(2).  
<https://doi.org/10.3390/agronomy12020230>
- Sun, J., Jameson, P. E., & Clemens, J. (2001). Water relations and stamen abscission in cut flowers of selected myrtaceae. *Acta Horticulturae*, 543.  
<https://doi.org/10.17660/ActaHortic.2001.543.22>
- Terry, L. A., & Joyce, D. C. (2004). Elicitors of induced disease resistance in postharvest horticultural crops: A brief review. In *Postharvest Biology and Technology* (Vol. 32, Issue 1).  
<https://doi.org/10.1016/j.postharvbio.2003.09.016>
- Thakur, N. (2020). A review on the effect of storage methods and packaging material on the post-harvest longevity of cut flowers. *International Journal of Chemical Studies*, 8(3). <https://doi.org/10.22271/chemi.2020.v8.i3ah.9568>
- Tilahun, S., Soon, J. C., & Su, P. Do. (2016). Influence of pulsing biocides on vase life of cut roses (*Rosa hybrida* L.). *Science, Technology and Arts Research Journal*, 4(3). <https://doi.org/10.4314/star.v4i3.12>
- Tinebra, I., Sortino, G., Inglese, P., Fretto, S., & Farina, V. (2021). Effect of Different Modified Atmosphere Packaging on the Quality of Mulberry Fruit (*Morus alba* L. cv Kokuso 21). *International Journal of Food Science*, 2021.  
<https://doi.org/10.1155/2021/8844502>
- Tonooka, M., Homma, Y., Toyoizumi, T., & Ichimura, K. (2023). Stem bending in cut gerbera under the condition of suppressing bacterial proliferation is associated with the weakening of the stem strength. *Scientia Horticulturae*, 319, 112153. <https://doi.org/10.1016/J.SCIENTA.2023.112153>
- Tripathi, S. K., & Tuteja, N. (2007). Integrated signaling in flower senescence: An overview. In *Plant Signaling and Behavior* (Vol. 2, Issue 6).  
<https://doi.org/10.4161/psb.2.6.4991>
- Van Doorn, W. G. (2004). Is Petal Senescence Due to Sugar Starvation? In *Plant Physiology* (Vol. 134, Issue 1). <https://doi.org/10.1104/pp.103.033084>
- Van Doorn, W. G. (2012). Water relations of cut flowers: An update. *Horticultural Reviews*, 40(1). <https://doi.org/10.1002/9781118351871.ch2>

- van Doorn, W. G., & de Witte, Y. (1991a). Effect of bacterial suspensions on vascular occlusion in stems of cut rose flowers. *Journal of Applied Bacteriology*, 71(2). <https://doi.org/10.1111/j.1365-2672.1991.tb02965.x>
- van Doorn, W. G., & de Witte, Y. (1991b). Effect of bacterial suspensions on vascular occlusion in stems of cut rose flowers. *Journal of Applied Bacteriology*, 71(2). <https://doi.org/10.1111/j.1365-2672.1991.tb02965.x>
- van Doorn, W. G., de Witte, Y., & Harkema, H. (1995). Effect of high numbers of exogenous bacteria on the water relations and longevity of cut carnation flowers. *Postharvest Biology and Technology*, 6(1–2), 111–119. [https://doi.org/10.1016/0925-5214\(94\)00043-R](https://doi.org/10.1016/0925-5214(94)00043-R)
- Van Doorn, W. G., & Woltering, E. J. (2004). Senescence and programmed cell death: Substance or semantics? In *Journal of Experimental Botany* (Vol. 55, Issue 406). <https://doi.org/10.1093/jxb/erh264>
- van Doorn, W. G., Zagory, D., de Witte, Y., & Harkema, H. (1991). Effects of vase-water bacteria on the senescence of cut carnation flowers. *Postharvest Biology and Technology*, 1(2). [https://doi.org/10.1016/0925-5214\(91\)90008-Y](https://doi.org/10.1016/0925-5214(91)90008-Y)
- van Gorsel, R., & Ravesloot, M. (2019). 847 PB 515 SHORT INTERRUPTIONS OF THE COLD CHAIN REDUCE THE VASE LIFE OF ASTER ERICOIDES, CHRYSANTHEMUM, DIANTHUS, AND GYPSOPHILA CUT FLOWERS. *HortScience*, 29(5). <https://doi.org/10.21273/hortsci.29.5.554f>
- Van Meeteren, U. (1978). Water relations and keeping-quality of cut Gerbera flowers. I. The cause of stem break. *Scientia Horticulturae*, 8(1). [https://doi.org/10.1016/0304-4238\(78\)90071-7](https://doi.org/10.1016/0304-4238(78)90071-7)
- van Meeteren, U., Arévalo-Galarza, L., & van Doorn, W. G. (2006). Inhibition of water uptake after dry storage of cut flowers: Role of aspired air and wound-induced processes in Chrysanthemum. *Postharvest Biology and Technology*, 41(1), 70–77. <https://doi.org/10.1016/J.POSTHARVBIO.2006.03.005>
- Van Meeteren, U., Schouten, R. E., & Woltering, E. (2015). Predicting rose vase life in a supply chain. *Acta Horticulturae*, 1099. <https://doi.org/10.17660/actahortic.2015.1099.32>
- Van Meeteren, U., Van Gelder, H., & Van Ieperen, W. (1999). Reconsideration of the use of deionized water as vase water in postharvest experiments on cut flowers. *Postharvest Biology and Technology*, 17(3). [https://doi.org/10.1016/S0925-5214\(99\)00050-2](https://doi.org/10.1016/S0925-5214(99)00050-2)
- Vaslier, N., & Van Doorn, W. G. (2003). Xylem occlusion in bouvardia flowers: Evidence for a role of peroxidase and catechol oxidase. *Postharvest Biology and Technology*, 28(2). [https://doi.org/10.1016/S0925-5214\(02\)00197-7](https://doi.org/10.1016/S0925-5214(02)00197-7)
- Vesprini, J. L., & Pacini, E. (2005). Temperature-dependent floral longevity in two Helleborus species. *Plant Systematics and Evolution*, 252(1–2). <https://doi.org/10.1007/s00606-004-0261-9>
- Vukosavljev, M., Zhang, J., Esselink, G. D., van 't Westende, W. P. C., Cox, P., Visser, R. G. F., Arens, P., & Smulders, M. J. M. (2013). Genetic diversity and differentiation in roses: A garden rose perspective. *Scientia Horticulturae*, 162. <https://doi.org/10.1016/j.scienta.2013.08.015>

- Wilczyńska, A., Kukułowicz, A., & Lewandowska, A. (2023). Effect of Packaging on Microbial Quality of Edible Flowers During Refrigerated Storage. *Polish Journal of Food and Nutrition Sciences*, 73(1). <https://doi.org/10.31883/pjfns/159037>
- Wu, M. J., van Doorn, W. G., & Reid, M. S. (1991). Variation in the senescence of carnation (*Dianthus caryophyllus* L.) cultivars. I. Comparison of flower life, respiration and ethylene biosynthesis. *Scientia Horticulturae*, 48(1–2). [https://doi.org/10.1016/0304-4238\(91\)90156-S](https://doi.org/10.1016/0304-4238(91)90156-S)
- Zagory, D., & Reid, M. S. (2022). Role of Vase Solution Microorganisms in the Life of Cut Flowers. *Journal of the American Society for Horticultural Science*, 111(1). <https://doi.org/10.21273/jashs.111.1.154>
- Zamski, E., Starkman, F., & Zieslin, N. (1991). Mechanical strength and anatomical structure of the peduncles of rose (*Rosa x hybrida*) flowers. *Israel Journal of Botany*, 40(1). <https://doi.org/10.1080/0021213X.1991.10677172>
- Zhuang, J., Qiao, L., Zhang, X., Su, Y., & Xia, Y. (2021). Effects of visual attributes of flower borders in urban vegetation landscapes on aesthetic preference and emotional perception. *International Journal of Environmental Research and Public Health*, 18(17). <https://doi.org/10.3390/ijerph18179318>

## Appendices

**Table 4. ANOVA table for bent necks during the time.** Results of bent necks (%) for 'Golden Smile' and 'Revival Sweet' roses at different drying lengths and days were analysed with general ANOVA.

| Source of variation          | df  | s.s      | m.s.    | F      | P value |
|------------------------------|-----|----------|---------|--------|---------|
| Drying length                | 3   | 4174.92  | 1391.64 | 181.06 | <.001   |
| Cultivar                     | 1   | 2275.81  | 2275.81 | 296.10 | <.001   |
| Day                          | 20  | 63935.15 | 3196.76 | 415.92 | <.001   |
| Drying length. Cultivar      | 3   | 261.42   | 87.14   | 11.34  | <.001   |
| Drying length. Day           | 60  | 13128.21 | 218.80  | 28.47  | <.001   |
| Cultivar. Day                | 20  | 10761.34 | 538.07  | 70.01  | <.001   |
| Drying length. Cultivar. Day | 60  | 2791.70  | 46.53   | 6.05   | <.001   |
| Residual                     | 502 | 3858.33  | 7.69    |        |         |
| Total                        | 669 | 99632.99 |         |        |         |

On the tables, df means "the degrees of freedom in the source." "s.s, "the sum of squares due to the source." M.s. "the mean sum of squares due to the source and " F, "the F-statistic" and P value <.001 shows the significant difference at 1%.

**Table 5. ANOVA table for damaged flowers.** Results of damaged flowers (%) for 'Golden Smile' and 'Revival Sweet' roses at different drying lengths and days were analysed with general ANOVA.

| Source of variation          | df  | s.s       | m.s.     | v.r     | P value |
|------------------------------|-----|-----------|----------|---------|---------|
| Drying length                | 3   | 29058.33  | 9686.11  | 551.62  | <.001   |
| Cultivar                     | 1   | 7202.38   | 7202.38  | 410.17  | <.001   |
| Day                          | 20  | 834084.23 | 41704.21 | 2375.02 | <.001   |
| Drying length. Cultivar      | 3   | 1541.67   | 513.89   | 29.27   | <.001   |
| Drying length. Day           | 60  | 28422.92  | 473.72   | 26.98   | <.001   |
| Cultivar. Day                | 20  | 9428.87   | 471.44   | 26.85   | <.001   |
| Drying length. Cultivar. Day | 60  | 8952.08   | 149.20   | 8.50    | <.001   |
| Residual                     | 504 | 8850.00   | 17.56    |         |         |
| Total                        | 671 | 927540.48 |          |         |         |

**Table 6. ANOVA table for solution uptake.** Results of solution uptake (mL/vase) for 'Golden Smile' and 'Revival Sweet' roses at different drying lengths and days were analysed with general ANOVA.

| Source of variation          | df  | s.s      | m.s.    | v.r    | P Value |
|------------------------------|-----|----------|---------|--------|---------|
| Drying length                | 3   | 2942281  | 980760  | 372.98 | <.001   |
| Cultivar                     | 1   | 1242     | 1242    | 0.47   | 0.493   |
| Day                          | 10  | 20444254 | 2044425 | 777.48 | <.001   |
| Drying length. Cultivar      | 3   | 59623    | 19874   | 7.56   | <.001   |
| Drying length. Day           | 30  | 332201   | 11073   | 4.21   | 0.186   |
| Cultivar. Day                | 10  | 36476    | 3648    | 1.39   | 1.000   |
| Drying length. Cultivar. Day | 30  | 24167    | 806     | 0.31   |         |
| Residual                     | 262 | 688944   | 2630    |        |         |
| Total                        | 349 | 23082796 |         |        |         |

**Table 7. ANOVA Table for Bud diameter.** Results of bud diameter (cm) for 'Golden Smile' and 'Revival Sweet' roses at different drying lengths and days were analysed with general ANOVA.

| Source of variation          | df  | s.s    | m.s.  | v.r     | P value |
|------------------------------|-----|--------|-------|---------|---------|
| Drying length                | 3   | 9.93   | 3.31  | 54.05   | <.001   |
| Cultivar                     | 1   | 68.67  | 68.67 | 1121.16 | <.001   |
| Day                          | 10  | 141.93 | 14.19 | 231.75  | <.001   |
| Drying length. Cultivar      | 3   | 1.14   | 0.38  | 6.20    | <.001   |
| Drying length. Day           | 30  | 0.97   | 0.03  | 0.53    | 0.981   |
| Cultivar. Day                | 10  | 28.35  | 2.83  | 46.29   | <.001   |
| Drying length. Cultivar. Day | 30  | 0.93   | 0.03  | 0.51    | 0.986   |
| Residual                     | 263 | 16.11  | 0.06  |         |         |
| Total                        | 350 | 230.34 |       |         |         |

**Table 8. ANOVA table for bent necks.** Results of bent necks (%) for 'Revival Sweet' roses at different drying and hydration lengths and days were analysed with general ANOVA.

| Source of variation                  | df  | s.s       | m.s.    | F      | P value |
|--------------------------------------|-----|-----------|---------|--------|---------|
| Drying length                        | 1   | 1701.39   | 1701.39 | 37.69  | <.001   |
| Hydration-length                     | 3   | 10225.00  | 3408.33 | 75.51  | <.001   |
| Day                                  | 8   | 74844.44  | 9355.56 | 207.26 | <.001   |
| Drying length. Hydration length      | 3   | 68.06     | 22.69   | 0.50   | 0.681   |
| Drying length. Day                   | 8   | 1536.11   | 192.01  | 4.25   | <.001   |
| Hydration Length. day                | 24  | 6800.00   | 283.33  | 6.28   | <.001   |
| Drying length. Hydration length. day | 24  | 319.44    | 13.31   | 0.29   | 1.000   |
| Residual                             | 216 | 9750.00   | 45.14   |        |         |
| Total                                | 287 | 105244.44 |         |        |         |

**Table 9. ANOVA table for damaged flowers.** Results of damaged flowers (%) for 'Revival Sweet' roses at different drying and hydration lengths and days were analysed with general ANOVA.

| Source of variation                  | df | s.s       | m.s.     | F      | P value |
|--------------------------------------|----|-----------|----------|--------|---------|
| Drying length                        | 1  | 3542.01   | 3542.01  | 63.89  | <.001   |
| Hydration length                     | 3  | 23159.37  | 7719.79  | 139.25 | <.001   |
| Day                                  | 8  | 90038.19  | 11254.77 | 203.01 | <.001   |
| Drying length. Hydration length      | 3  | 234.38    | 78.13    | 1.41   | 0.241   |
| Drying length. Day                   | 8  | 1754.86   | 219.36   | 3.96   | <.001   |
| Hydration Length. day                | 24 | 14981.25  | 624.22   | 11.26  | <.001   |
| Drying length. Hydration length. day | 24 | 431.25    | 17.97    |        | 0.999   |
| Residual                             | 21 | 11975.00  | 55.44    |        |         |
|                                      | 6  |           |          |        |         |
| Total                                | 28 | 146116.32 |          |        |         |
|                                      | 7  |           |          |        |         |

**Table 10. ANOVA table for solution uptake.** Results of solution uptake (mL/vase) for 'Revival Sweet' roses at different drying and hydration lengths and days were analysed with general ANOVA.

| Source of variation                  | df  | s.s       | m.s.      | F       | P value |
|--------------------------------------|-----|-----------|-----------|---------|---------|
| Drying length                        | 1   | 97557.6   | 97557.6   | 193.55  | <.001   |
| Hydration length                     | 3   | 176671.1  | 58890.4   | 116.84  | <.001   |
| Day                                  | 6   | 6346075.6 | 1057679.3 | 2098.40 | <.001   |
| Drying length. Hydration length      | 3   | 7129.7    | 2376.6    | 4.72    | 0.003   |
| Drying length. Day                   | 6   | 15366.0   | 2561.0    | 5.08    | <.001   |
| Hydration Length. day                | 18  | 90863.9   | 5048.0    | 10.02   | <.001   |
| Drying length. Hydration length. day | 18  | 9648.8    | 536.0     | 1.06    | 0.393   |
| Residual                             | 168 | 84678.8   | 504.0     |         |         |
| Total                                | 223 | 6736783.0 |           |         |         |

**Table 11. ANOVA table for bud diameter during time.** Results of bud diameter (cm) for 'Revival Sweet' roses at different drying lengths (96 and 168 hours) and 24 hours of hydration during time were analysed with two-way ANOVA.

| Source of variation | df | s.s    | m.s.      | F       | P value |
|---------------------|----|--------|-----------|---------|---------|
| Drying length       | 1  | 9.46   | 9.465331  | 1197.16 | <.001   |
| Day                 | 6  | 142.44 | 23.740146 | 3002.62 | <.001   |
| Drying length. day  | 6  | 6.64   | 1.106233  | 139.91  | <.001   |
| Residua             | 42 | 0.33   | 0.007906  |         |         |
| Total               | 55 | 158.87 |           |         |         |

**Table 12. ANOVA table for bud diameter on day 18.** Results of bud diameter (cm) for 'Revival Sweet' roses at different drying (96 and 168 hours) and hydration (0, 12, 24 and 48 hours) lengths on day 18 were analysed with two-way ANOVA.

| Source of variation             | df | s.s   | m.s.     | F       | P value |
|---------------------------------|----|-------|----------|---------|---------|
| Drying length                   | 1  | 2.50  | 2.503763 | 338.57  | <.001   |
| Hydration length                | 3  | 28.32 | 9.441013 | 1276.67 | <.001   |
| Drying length. Hydration length | 3  | 18.62 | 6.206125 | 839.23  | <.001   |
| Residual                        | 24 | 0.18  | 0.007395 |         |         |
| Total                           | 31 | 49.62 |          |         |         |

**Table 13. ANOVA table for vase water pH during time.** Results of vase water pH for 'Revival Sweet' roses at different drying lengths (96 and 168 hours) and 24 hours of hydration during time were analysed with two-way ANOVA.

| Source of variation | df | s.s  | m.s. | v.r    | P value |
|---------------------|----|------|------|--------|---------|
| Drying length       | 1  | 0.13 | 0.13 | 54.28  | <.001   |
| Day                 | 6  | 8.41 | 1.40 | 575.79 | <.001   |
| Drying length. Day  | 6  | 0.24 | 0.04 | 16.44  | <.001   |
| Residual            | 40 | 0.10 | 0.00 |        |         |
| Total               | 53 | 8.31 |      |        |         |

**Table 14. ANOVA table for roses vase water pH on day 18.** Results of vase water pH for 'Revival Sweet' roses at different drying (96 and 168 hours) and hydration (0, 12, 24, and 48 hours) lengths on day 18 were analysed with two-way ANOVA.

| Source of variation            | df | s.s  | m.s. | F      | P value |
|--------------------------------|----|------|------|--------|---------|
| Drying length                  | 1  | 0.01 | 0.01 | 0.71   | 0.407   |
| Condition length               | 3  | 9.49 | 3.16 | 164.27 | <.001   |
| Drying length condition length | 3  | 0.03 | 0.01 | 0.59   | 0.630   |
| Residual                       | 23 | 0.44 | 0.02 |        |         |
| Total                          | 30 | 9.80 |      |        |         |

**Table 15. ANOVA table for aerobic colony count in vase water during time.** Results of aerobic colony plate count for 'Revival Sweet' roses at different drying lengths (96 and 168 hours) and 24 hours of hydration during time were analysed with two-way ANOVA.

| Source of variation | df  | s.s    | m.s.  | v.r      | P value |
|---------------------|-----|--------|-------|----------|---------|
| Drying length       | 1   | 435.88 | 72.65 | 70366.54 | <.001   |
| Day                 | 6   | 0.17   | 0.17  | 166.54   | <.001   |
| Drying length. Day  | 6   | 0.04   | 0.01  | 6.44     | <.001   |
| Residual            | 154 | 0.16   | 0.00  |          |         |
| Total               | 167 | 436.25 |       |          |         |

**Table 16. ANOVA table for aerobic colony count in vase water on day 18.** Results vase water aerobic colony count for 'Revival Sweet' roses at different drying (96 and 168 hours) and hydration (0, 12, 24, and 48 hours) lengths on day 18 were analysed with two-way ANOVA.

| Source of variation            | df | s.s   | m.s.  | F      | P value |
|--------------------------------|----|-------|-------|--------|---------|
| Drying length                  | 1  | 0.42  | 0.42  | 104.57 | <.001   |
| Condition length               | 3  | 10.16 | 3.30  | 853.24 | <.001   |
| Drying length condition length | 3  | 0.37  | 0.12  | 30.85  | <.001   |
| Residual                       | 88 | 0.35  | 0.003 |        |         |
| Total                          | 95 | 11.29 |       |        |         |

**Table 17. ANOVA table for individual sugars.** individual sugars (a: sucrose, b: fructose and c: glucose) in petals of flowers with the 24 hours hydration length and different drying lengths (96 and 168 hours) and days.

a). sucrose

| Source of variation | df | s.s     | m.s.    | F     | P value |
|---------------------|----|---------|---------|-------|---------|
| Drying length       | 1  | 18.065  | 18.065  | 7.16  | 0.011   |
| Day                 | 6  | 846.733 | 141.122 | 55.94 | <.001   |
| Drying length. day  | 6  | 7.780   | 1.297   | 0.51  | 0.794   |
| Residua             | 42 | 105.955 | 2.523   |       |         |
| Total               | 55 | 978.533 |         |       |         |

b). fructose

| Source of variation | df | s.s     | m.s.   | F     | P value |
|---------------------|----|---------|--------|-------|---------|
| Drying length       | 1  | 259.2   | 259.2  | 1.31  | 0.258   |
| Day                 | 6  | 14202.6 | 2367.1 | 11.99 | <.001   |
| Drying length. day  | 6  | 818.8   | 136.5  | 0.69  | 0.658   |
| Residua             | 42 | 8289.4  | 197.4  |       |         |
| Total               | 55 | 23570.0 |        |       |         |

## c). glucose

| Source of variation | df | s.s      | m.s.    | F     | P value |
|---------------------|----|----------|---------|-------|---------|
| Drying length       | 1  | 31.86    | 31.86   | 1.21  | 0.278   |
| Day                 | 6  | 11320.43 | 1886.74 | 71.50 | <.001   |
| Drying length. day  | 6  | 52.38    | 8.73    | 0.33  | 0.917   |
| Residua             | 42 | 1108.32  | 26.39   |       |         |
| Total               | 55 | 12512.99 |         |       |         |

**Table 18. ANOVA table for individual sugars.** Individual sugars (a: sucrose, b: fructose and c: glucose) in petals of flowers with different drying (96 and 168 hours) and hydration (0, 12, 24 and 48 hours) lengths were measured on day 18.

## a). sucrose

| Source of variation             | df | s.s     | m.s.    | F     | P value |
|---------------------------------|----|---------|---------|-------|---------|
| Drying length                   | 1  | 1.0472  | 1.0472  | 7.07  | 0.019   |
| Condition length                | 3  | 5.9674  | 1.9891  | 13.43 | <.001   |
| Drying length. Condition length | 3  | 44.3758 | 14.7919 | 99.87 | <.001   |
| Residual                        | 14 | 2.0737  | 0.1481  |       |         |
| Total                           | 21 | 33.9629 |         |       |         |

## b). fructose

| Source of variation             | df | s.s    | m.s.   | F     | P value |
|---------------------------------|----|--------|--------|-------|---------|
| Drying length                   | 1  | 1789.7 | 1789.7 | 16.95 | <.001   |
| Condition length                | 3  | 3516.6 | 1172.2 | 11.10 | <.001   |
| Drying length. Condition length | 3  | 4029.4 | 1343.1 | 12.72 | <.001   |
| Residual                        | 18 | 1900.4 | 105.6  |       |         |
| Total                           | 25 | 8961.3 |        |       |         |

## c). glucose

| Source of variation             | df | s.s     | m.s.   | F     | P value |
|---------------------------------|----|---------|--------|-------|---------|
| Drying length                   | 1  | 250.89  | 250.89 | 15.31 | <.001   |
| Condition length                | 3  | 558.21  | 186.07 | 11.35 | <.001   |
| Drying length. Condition length | 3  | 329.48  | 109.83 | 6.70  | 0.003   |
| Residual                        | 20 | 327.77  | 16.39  |       |         |
| Total                           | 27 | 1194.94 |        |       |         |

**Table 19. ANOVA table for objective colour during vase life.** Objective colour (a: Chroma (C\*), b: Lightness (L\*) and c: Hue angle (h°)) in petals of flowers with 24 hours hydration length, different drying lengths (96 and 168 hours) and days were measured.

## a). Chroma

| Source of variation | df | s.s     | m.s.   | F    | P value |
|---------------------|----|---------|--------|------|---------|
| Day                 | 6  | 105.507 | 17.584 | 9.29 | <.001   |
| Drying length       | 1  | 0.243   | 0.243  | 0.13 | 0.722   |
| Drying length. Day  | 6  | 38.806  | 6.468  | 3.42 | 0.008   |
| Residua             | 42 | 79.508  | 1.893  |      |         |
| Total               | 55 | 224.063 |        |      |         |

## b). Lightness

| Source of variation | df | s.s     | m.s.   | F     | P value |
|---------------------|----|---------|--------|-------|---------|
| Day                 | 6  | 112.833 | 18.805 | 12.90 | <.001   |
| Drying length       | 1  | 12.868  | 12.868 | 8.82  | 0.005   |
| Drying length. Day  | 6  | 32.168  | 5.361  | 3.68  | 0.005   |
| Residua             | 42 | 61.244  | 1.458  |       |         |
| Total               | 55 | 219.113 |        |       |         |

## c). Hue angle

| Source of variation | df | s.s     | m.s.   | F     | P value |
|---------------------|----|---------|--------|-------|---------|
| Day                 | 6  | 485.282 | 80.880 | 54.33 | <.001   |
| Drying length       | 1  | 20.252  | 20.252 | 13.60 | <.001   |
| Drying length. Day  | 6  | 18.727  | 3.121  | 2.10  | 0.074   |
| Residua             | 42 | 62.521  | 1.489  |       |         |
| Total               | 55 | 586.783 |        |       |         |

**Table 20. ANOVA table for objective colour on day 18.** Objective colour (a: Chroma (C\*), b: Lightness (L\*) and c: Hue angle (h°)) in petals of flowers with different drying and hydration lengths were measured on day 18.

## a). Chroma

| Source of variation             | df | s.s     | m.s.   | F     | P value |
|---------------------------------|----|---------|--------|-------|---------|
| Hydration length                | 3  | 28.071  | 9.357  | 2.57  | 0.078   |
| Drying length                   | 1  | 42.695  | 42.695 | 11.72 | 0.002   |
| Hydration length. drying length | 3  | 16.812  | 5.604  | 1.54  | 0.230   |
| Residual                        | 24 | 87.443  | 3.643  |       |         |
| Total                           | 31 | 175.021 |        |       |         |

## b). Lightness

| Source of variation             | df | s.s     | m.s.   | F    | P value |
|---------------------------------|----|---------|--------|------|---------|
| Hydration length                | 3  | 16.477  | 5.492  | 1.76 | 0.182   |
| Drying length                   | 1  | 8.598   | 8.598  | 2.75 | 0.110   |
| Hydration length. drying length | 3  | 74.709  | 24.903 | 7.96 | <.001   |
| Residual                        | 24 | 75.054  | 3.127  |      |         |
| Total                           | 31 | 174.839 |        |      |         |

## c). Hue angle

| Source of variation             | df | s.s     | m.s.   | F     | P value |
|---------------------------------|----|---------|--------|-------|---------|
| Hydration length                | 3  | 21.512  | 7.171  | 2.99  | 0.051   |
| Drying length                   | 1  | 24.415  | 24.415 | 10.17 | 0.004   |
| Hydration length. drying length | 3  | 24.768  | 8.256  | 3.44  | 0.033   |
| Residual                        | 24 | 57.590  | 2.400  |       |         |
| Total                           | 31 | 128.284 |        |       |         |