Nitrate surveillance: Results

Sample Overview by Region

A total of 202 domestic samples were collected between April 2021 and March 2022 (**Figure 1**). For England, 9 samples were collected from the North East, 21 samples from the North West, 46 from Central England, 23 samples from the East and East Anglia, 48 from South East England and 18 samples from the South West. 10 samples were collected from Wales, 16 samples from Scotland and 11 samples from Northern Ireland.

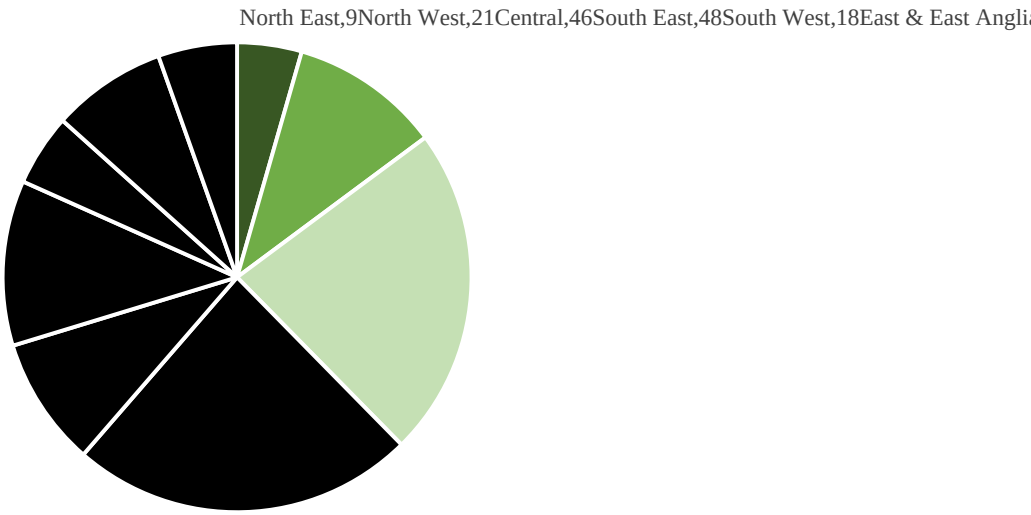

Figure 1. Total counts for samples collected from each region between April 2021 and March 2022.

Summary figures for nitrate concentrations are given in **Table 4**. Four regions had samples with nitrate concentrations below the detectable threshold of 50 mg/kg (North East, Central and South West England, and Northern Ireland). The highest minimum concentration was recorded in Wales (1063.1 mg/kg). Wales also showed the highest average concentration within a region (3515.6 mg/kg) compared with a national average of 2031.9 mg/kg. Two regions were substantially below the national average – the North East (1112.7 mg/kg) and Scotland (1262.6 mg/kg). The highest maximum concentration was recorded in Central England (7046.9 mg/kg), although Wales also recorded significantly high maximum samples (6599.6 mg/kg).

Table 4. Summary nitrate concentration figures by region between April 2021 and March 2022.

Region	Minimum NO_3 Content (mg/kg)	Average NO_3 Content (mg/kg)	Maximum NO_3 Content (mg/kg)
North East	<50	1112.7	4293.6
North West	350	2220.0	4390.1
Central	<50	1970.6	7046.9
South East	51.2	1867.2	4350.1
South West	<50	2156.6	5540.6
East & East Anglia	149	2348.2	5548.6
Scotland	458.4	1262.6	2451.4
N Ireland	<50	2304.5	4620.5
Wales	1063.1	3515.6	6599.6

Values are given in **Table 5** for the number of samples in each region approaching 10% of the maximum threshold, and exceeding the maximum threshold for the corresponding nitrate concentration. Four regions had no samples that were within 10% of the maximum threshold (north east, North West and South West England and Scotland). Only 1 sample exceeded the maximum threshold in central and South East England, East Anglia, and Northern Ireland. Wales had the greatest number of samples which exceeded the maximum thresholds, with 3 of 10 samples exceeding the threshold. Overall, 11 samples were within 10% of the maximum threshold, and 7 samples from a total of 202 exceeded the maximum threshold for the corresponding product type.

Table 5. Regional counts of samples approach 10%, and exceeding, the maximum threshold for corresponding category type.

Region	Total Count	Count within 10% of Maximum	Count Above Maximum Threshold	Percentage of Samples Above Maximum Threshold (%)
North East	9	0	0	0.0
North West	21	0	0	0.0
Central	46	2	1	2.2
South East	48	1	1	2.1
South West	18	0	0	0.0
East & East Anglia	23	2	1	4.3
Scotland	16	0	0	0.0
N Ireland	11	2	1	9.1
Wales	10	4	3	30.0
Total	202	11	7	3.5

Sample Overview by Category

A summary of samples collected by category is given in **Table 6**. The majority of samples were open air non-iceberg lettuce sampled in the summer (49) and protected non-iceberg lettuce sampled in the winter (45). Overall, the majority of samples were of the non-iceberg type (112) with only 18 samples of iceberg-type lettuce collected. Only 9 samples each were collected from open air non-iceberg lettuce sampled in the winter, and protected non-iceberg lettuce sampled in the summer. 26 spinach samples and 9 rocket samples were collected in total.

37 samples categorised as Other Green Leafy Vegetables were collected. This included 6 samples of cabbage, 5 samples of kale alongside Mizuna (4 samples), Red Chard (4), Chinese Leaves (4), Mustard (3), Pak Choi (3), Celery (2), Red Mizuna (2) and single samples of Bulls

Blood, Komatsuna Multi-leaf and Red Batavia.

The distribution of samples between category type this season was largely comparable with past seasons. A slight increase in the proportion of non-iceberg type open air lettuce was sampled in 2021-22 compared with 2020-2021 (24.3% vs. 20.9%), largely due to a reduction in the Other Green Leafy Vegetable category (18.3 vs. 23.9%).

Table 6. Summary of sample counts per category, cultivation type and harvest period.

Category	Cultivation	Harvest Period	Count
Lettuce – Non-Iceberg	Open Air	Summer	49
Lettuce – Non-Iceberg	Open Air	Winter	9
Lettuce – Non-Iceberg	Protected	Summer	9
Lettuce – Non-Iceberg	Protected	Winter	45
Lettuce – Iceberg	Open Air	Summer	18
Spinach	n/a	n/a	26
Rocket	n/a	Summer	6
Rocket	n/a	Winter	3
Other Leafy Green Vegetables	n/a	n/a	37

Overview of Nitrate Concentrations

130 lettuce samples were collected, comprising of 18 open air summer iceberg samples, 54 protected non-iceberg types (9 summer, 45 winter) and 58 open air non-iceberg types (49 summer and 9 winter).

Significant variation was seen in nitrate content for lettuce with both season, product type and production method impacting recorded nitrate levels (**Figure 2**, **Table 7**). Levels were relatively low in open air iceberg-type lettuce, with the lowest average nitrate concentration of all category types of 935 mg/kg. Levels were also the most consistent across the season.

Non-iceberg types grown in the open air showed a broader range of nitrate concentrations, ranging from <50 mg/kg to 3250 mg/kg in the summer, and 1037 – 2917 mg/kg in the winter. Average nitrate concentrations in open air non-iceberg types was 1200 mg/kg.

Non-iceberg types grown under protection showed the greatest nitrate concentrations within the salad leaf categories, with the greatest concentration of 5548 mg/kg which was recorded in a winter sample. The average protected non-iceberg type concentration was 3062 mg/kg. Concentrations in protected non-iceberg types were higher in the winter period, ranging from 876 – 5549 mg/kg, compared with 597 – 4620 mg/kg in the summer. Elevated nitrate levels in the winter, particularly in protected samples are likely as a result of lower light levels. Research indicates that lettuce may accumulate nitrate at higher concentrations at lower light levels to aid the plants ability to modulate internal osmotic balance (Blom-Zandstra et al., 1985). Whilst light levels are likely to be a primary driver of this, there is also potential interaction with cultivation system. Protected crops are likely to be exposed to a more consistent external solute concentration (and one which may internally be kept low to drive growth), and with increased rates of transpiration due to supplementary heat provision, which will increase nitrate uptake compared with more inconsistent conditions in open fields.

The accumulation of nitrate to act as an osmoticum will occur to enable plants to maintain favourable internal water volumes and solute concentrations during growth, including buffering environmental changes. A range of osmotica will be used for this including other salts and neutral solutes, and this could be exploited by cultural methods to reduce nitrate accumulation. The increase in nitrate accumulation in low light conditions is likely to counter the reduce availability of sugars due to declines in photosynthesis (Behr et al., 1992). Therefore, increasing light levels through supplementary lighting, increasing the proportion of ammonium used to provide total nitrogen or the harvesting of more mature plants (solute concentrations decline with age) (Burns et al., 2008) may help to reduce levels nitrate accumulation. More innovative approaches could include the application of alternative osmoticum to the roots – a study in which glycine betaine was applied through a fertigation solution led to significant reductions in nitrate accumulation in lettuce (Jokinen et al., 2022). Glycine betaine is already used commercially as a supplementary osmoticum to promote frost resistance in apple when applied as a foliar spray, and so its use could be extended into leafy salad production. These approaches remain experimental, however, and some studies have reported that similar interventions have not had a positive effect (e.g. McCall & Willumsen, 1999) but it would be beneficial to explore the potential positive impacts of these approaches in commercial-scale trials.

No iceberg samples approached 10% of the maximum thresholds. Four non-iceberg lettuce samples exceeded the nitrate threshold – two open air samples collected in the summer, and a winter and summer protected type. Two further winter and summer protected samples were within 10% of the maximum threshold.

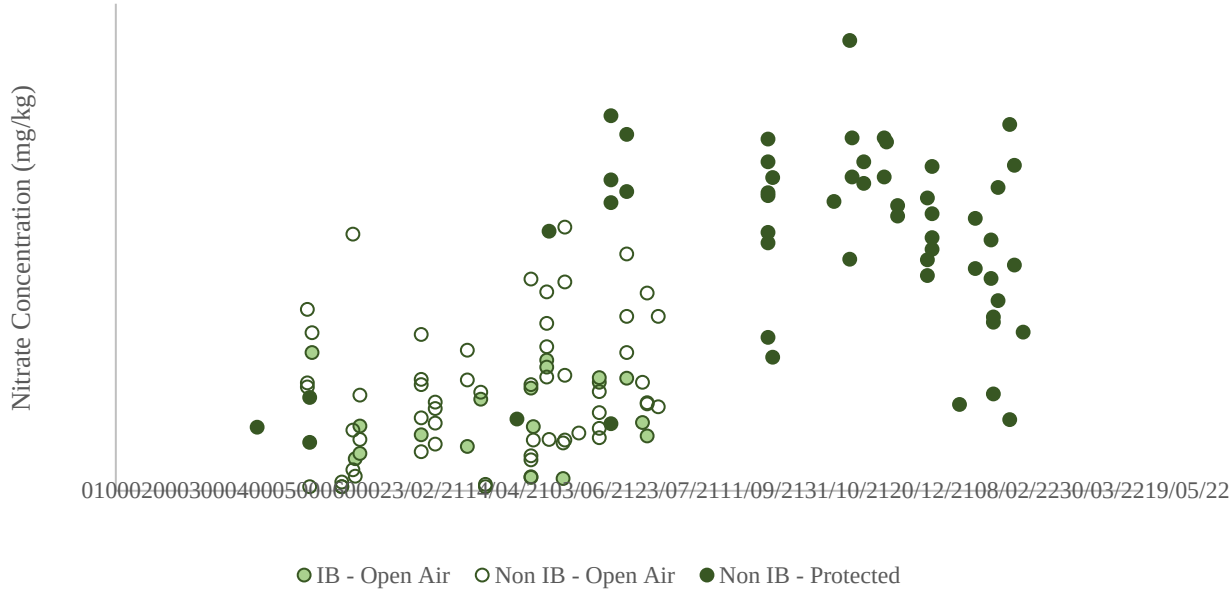

Figure 2. Seasonal nitrate concentrations for iceberg-type (IB) and non-iceberg type (Non-IB) lettuce grown under protection or in open air.

For Other Green Leafy Veg, average nitrate concentrations were 2526 mg/kg, ranging from <50 mg/kg to 7047 mg/kg (**Figure 3**, **Table 7**). Levels were generally lowest in cabbage (508 mg/kg) and highest in Mustard (5329 mg/kg) and Red Mizuna (6701 mg/kg). Levels were lowest in the summer period, increasing in the winter.

Figure 3. Seasonal nitrate concentrations for Other Green Leafy Veg.

For Rocket, average nitrate concentrations across the season were 2642 mg/kg, ranging from 614 – 6600 mg/kg (**Figure 4, Table 7**) although only a limited numbers of samples were collected meaning that it is difficult to compare changes in concentration across the season. One rocket sample was within 10% of the maximum threshold.

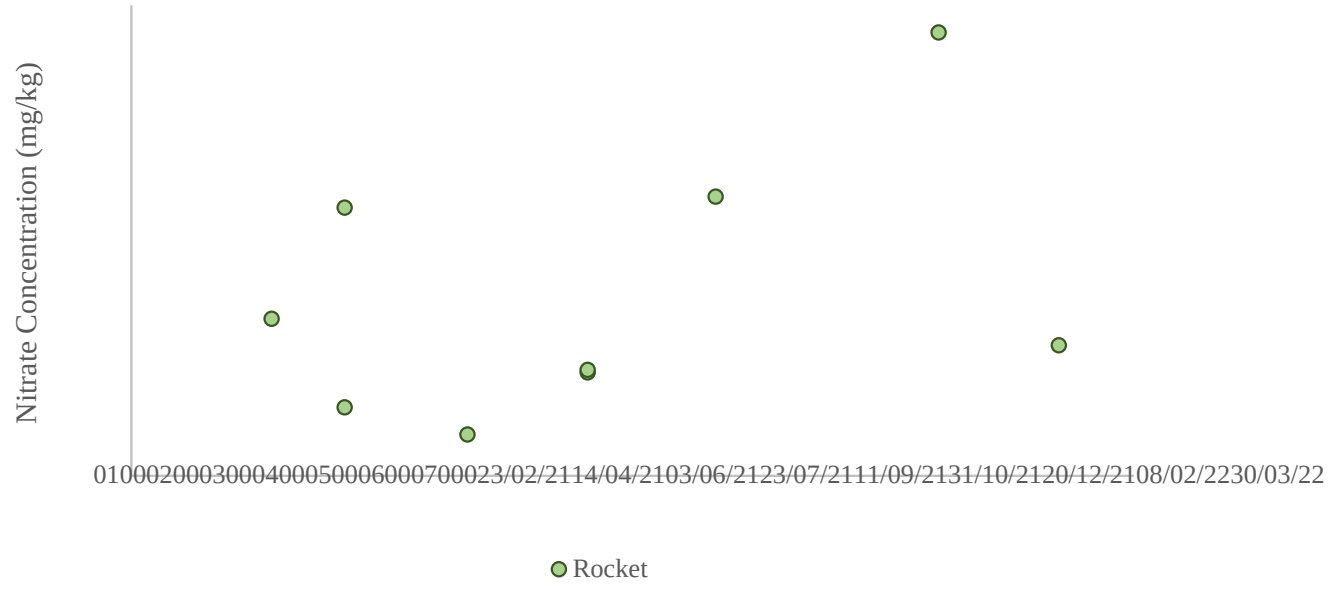

Figure 4. Seasonal nitrate concentrations for Rocket.

For spinach, average nitrate concentrations were 1594 mg/kg, ranging from 93 – 5814 mg/kg across the season (**Figure 5**, **Table 7**). Similar to lettuce, nitrate concentrations were greater in the winter period compared with the summer, and were more variable over this period compared with relatively close values for summer samples.

Three spinach samples exceeded the maximum nitrate threshold, and one further sample came within 10% of the maximum threshold.

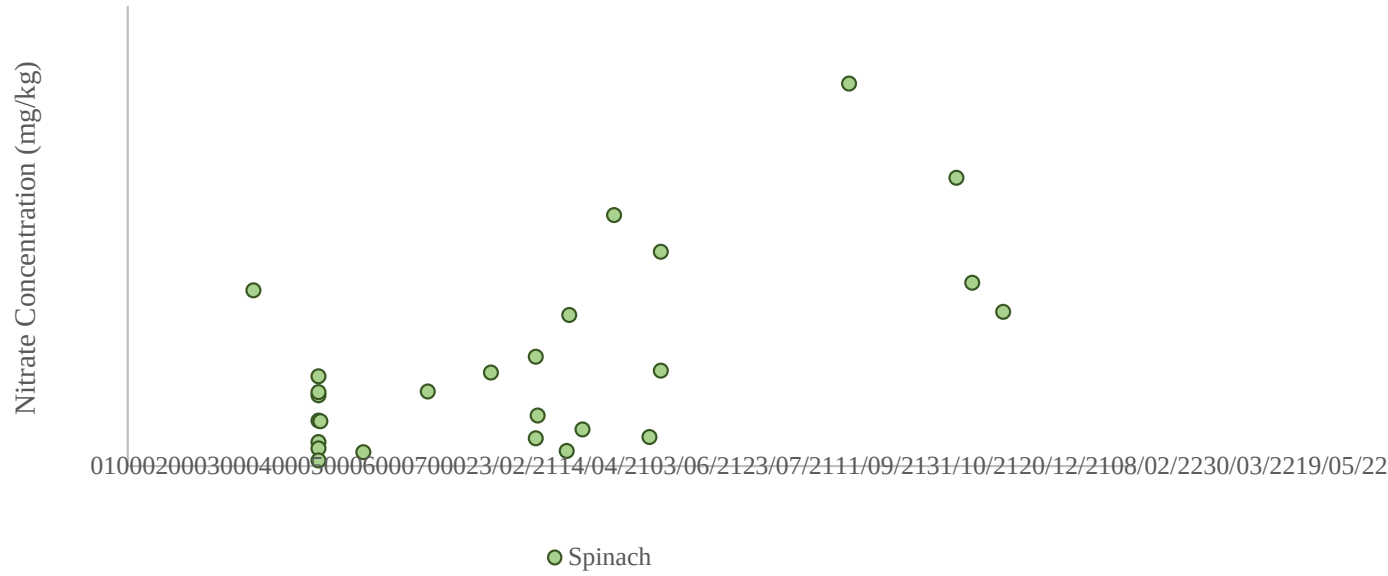

Figure 5. Seasonal nitrate concentrations for Spinach.

When compared against sample sizes, the greatest proportion of samples exceeding the threshold value for nitrate concentration were recorded for Spinach (3 of 26 samples, 11.5%) and protected non-iceberg lettuce sampled in the summer (1 of 9 samples, 11.1%). Summary figures are given in **Table 8**.

Table 7. Summary seasonal nitrate concentrations per category.

Category	Minimum Nitrate Concentration (mg/kg)	Average Nitrate Concentration (mg/kg)	Maximum Nitrate Concentration (mg/kg)
Iceberg	149.0	935.2	1701.3
Non-Iceberg – Open (Summer)	50.0	1096.5	3250.0
Non-Iceberg – Open (Winter)	1037.4	1763.1	2917.8
Non-Iceberg – Open (Season)	50.0	1200.0	3250.0
Non-Iceberg – Protected (Summer)	597.2	2158.9	4620.5
Non-Iceberg – Protected (Winter)	875.7	3242.2	5548.6
Non-Iceberg – Protected (Season)	597.2	3061.7	5548.6
Other Leafy Green Vegetables	>50.0	2526.1	7046.9
Rocket (Summer)	614.1	1846.7	3986.6
Rocket (Winter)	1942.7	4271.2	6599.6
Rocket (Season)	614.1	2642.3	6599.6
Spinach	92.6	1593.6	5814.3

Table 8. Summary figures for samples approaching 10% of, and exceeding, the maximum nitrate concentrations.

Product Type	Total Count	Count within 10% of Maximum	Count Above Maximum Threshold	Percentage of Samples Above Maximum Threshold (%)

Iceberg	18	0	0	0.0
Non-Iceberg – Open (Summer)	49	2	2	4.1
Non-Iceberg – Open (Winter)	9	0	0	0.0
Non-Ice – Protected (Summer)	9	2	1	11.1
Non-Ice – Protected (Winter)	45	2	1	2.2
Other Leafy Green Vegetables	37	n/a	n/a	n/a
Rocket (Summer)	6	0	0	0.0
Rocket (Winter)	3	1	0	0.0
Spinach	26	4	3	11.5
Total	202	11	7	5.4

Historical Trends

Average nitrate concentrations in iceberg lettuce grown in the open air in 2021 were consistent with long-term means for this category (935 vs. 931 mg/kg - **Figure 6**). Whilst this is consistent with samples taken in 2017 and 2018, this does not correlate with the 2020 average. However, given the differing sampling strategy in 2020 due to the covid-19 epidemic this year may not be representative of longer term averages.

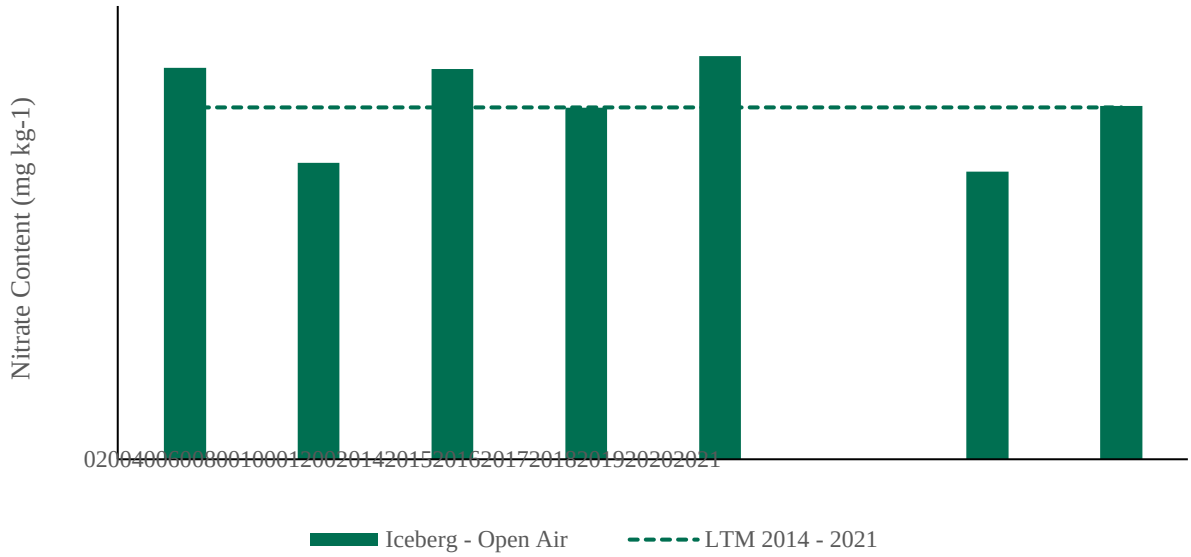

Figure 6. Comparison of annual average nitrate concentrations for outdoor iceberg-type lettuce compared with the long-term mean (LTM).

For non-iceberg types grown in the open air, summer samples in 2021 were significantly below the long term mean (1096 vs. 1245 mg/kg), whilst winter samples were marginally above the long term mean (1763 vs. 1674 mg/kg - **Figure 7**), this is the reverse trend seen from the 2020 although this is likely to have impacted by sampling strategy differences between the two seasons – only three samples were collected in January 2021 . In 2021 the difference between summer and winter samples of open air non-iceberg types was substantial (1096 vs. 1763 mg/kg, an increase of 60.9% between summer and winter), following similar relationships seen between summer and winter samples seen since 2014 except 2016 and 2020.

For protected non-iceberg types, both summer and winter samples were below long term means (**Figure 8**). The summer average in 2021 was 2159 mg/kg compared with a long term mean of

2768 mg/kg. Winter averages were 3382 and 3191 mg/kg in 2021 and 2022 respectively compared with a long term mean of 3500 mg/kg. In 2021 the increase from summer to winter samples was substantial – 1223 mg/kg, an increase of 56.6% - and a continuation of a trend of increasing discrepancies between summer and winter grown samples since 2019. However, given that winter levels have also declined, this reduction is most likely as a result of more consistent growing environments in the winter months leading to increased control of nutrient uptake and management.

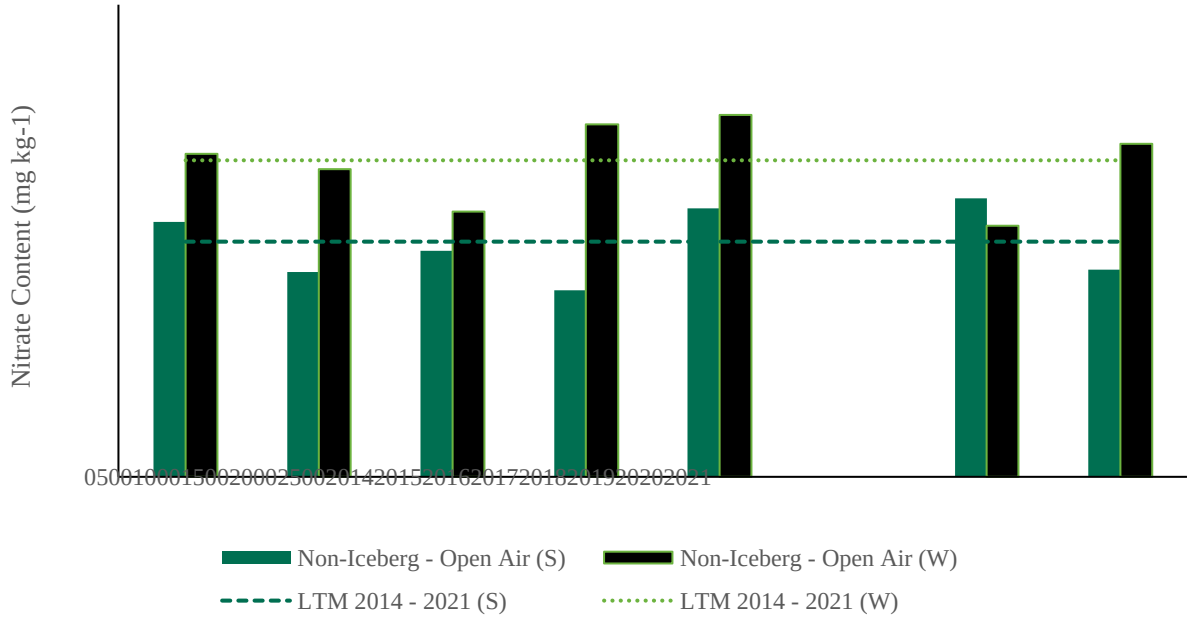

Figure 7. Comparison of annual average nitrate concentrations for outdoor non iceberg-type lettuce compared with the long-term mean (LTM).

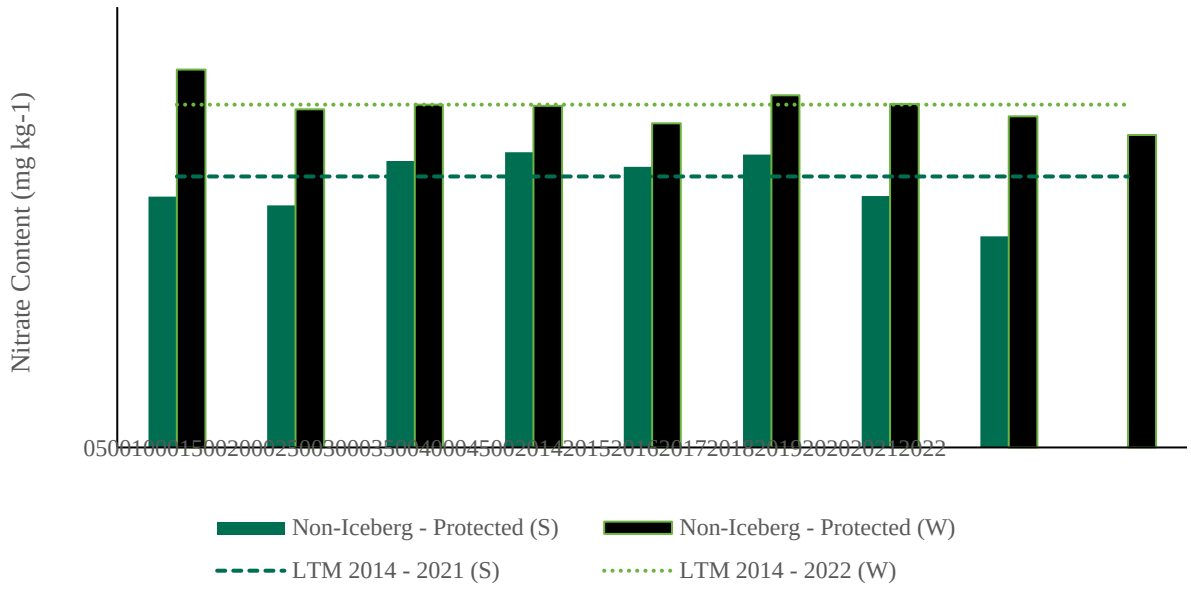

Figure 8. Comparison of annual average nitrate concentrations for protected non iceberg-type lettuce compared with the long-term mean (LTM).

Average nitrate concentrations in rocket were marginally lower than the long term mean (3809 vs. 4100 mg/kg - **Figure 9**). Average nitrate levels in Spinach in 2022 were almost double the long term mean (3833 vs. 1722 mg/kg - **Figure 10**). However, it should be noted that the 2022 average was based on only two samples (6600 and 1943 mg/kg) so that the presented average is likely to be impacted by sampling bias. Average concentrations in 2021 (1435 mg/kg based on 7 samples) were lower than the long term mean.

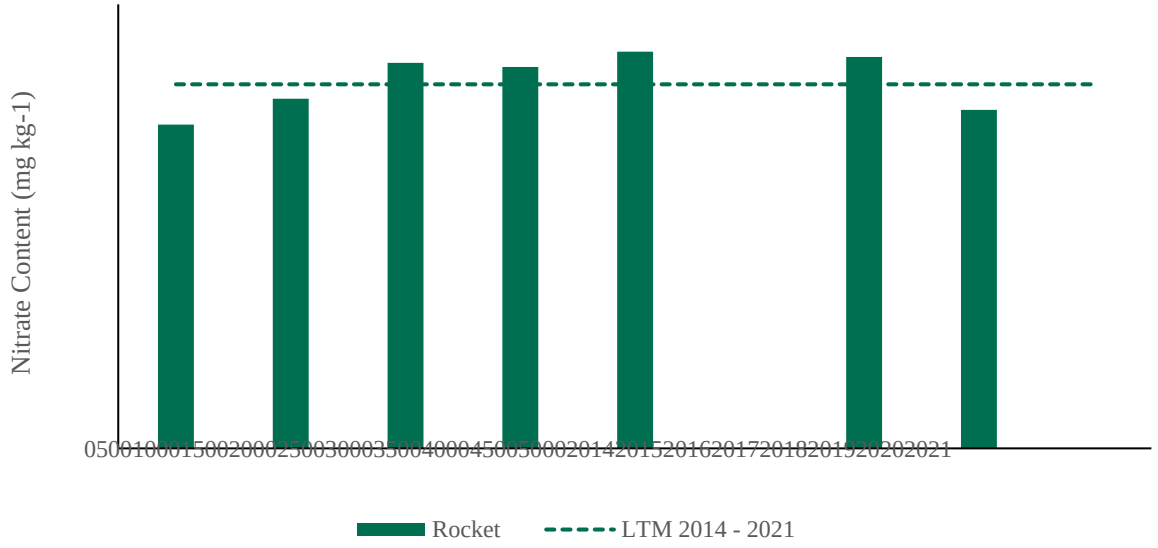

Figure 9. Comparison of annual average nitrate concentrations for rocket compared with the long-term mean (LTM).

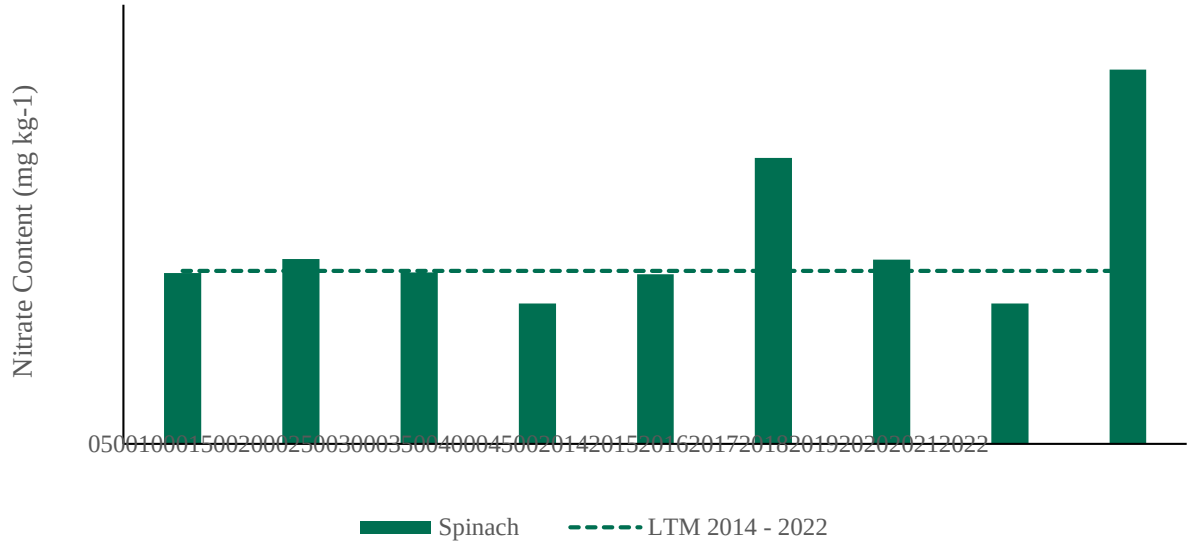

Figure 10. Comparison of annual average nitrate concentrations for spinach compared with the long-term mean (LTM).

Long term means for other leafy vegetables are not presented given variable sample group composition between years.

Samples Exceeding Regulation Limits

Four out of 125 samples (3.2%) collected in 2021 exceeded the regulation limit (NB. this value spans two report periods). The four exceedances were represented by two open air non-iceberg type samples, one protected non-iceberg sample and a spinach sample, all collected in the summer. A further three samples were within 10% of the maximum threshold in this period.

Whilst this is higher than 2020 (1.8%), this corresponds with the longer term trend of a decline in the proportions of samples exceeding regulated limits (**Figure 11**). Average percentages between 2002 – 2011 were 8.3% compared with 3.4% between 2012 – 2021.

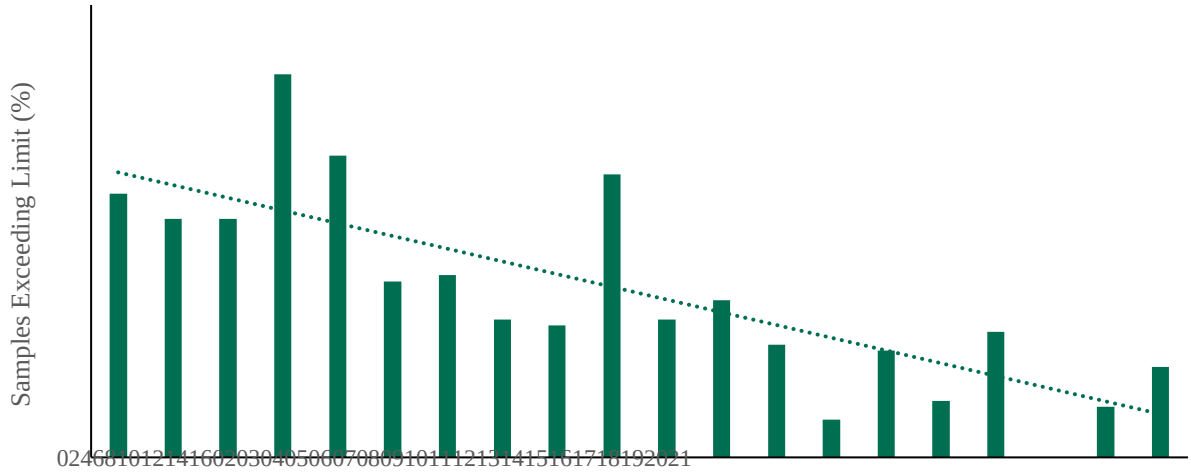

Figure 11. Annual percentages of UK samples collected between 2002 – 2021 which exceeded the regulation limit. Samples collected between Jan – March 2022 are not included. NB. Data for 2019 is not available.

When considered on a per-category basis, there have been no samples of open-air iceberg lettuce exceeding regulatory limits since 2014 (**Figure 12**). There has been a small but consistent proportion of open-air non-iceberg type lettuce which have exceeded regulatory limits in both 2020 and 2021, and this has increased from no samples in 2015-2017 (**Figure 13**). The proportion of protected non-iceberg type samples exceeding the regulatory levels in winter samples has remained at 0% since 2015. However, there have been relatively consistent exceedances in summer-sampled non-iceberg samples, although exceedances were the greatest in 2021 (11% of samples) since 2014 (**Figure 14**). There have been no exceedances in rocket since 2018 (**Figure 15**). Exceedance in spinach in 2021 had decreased compared with 2020 (reduced from 9.1% to 3.8% - **Figure 16**).

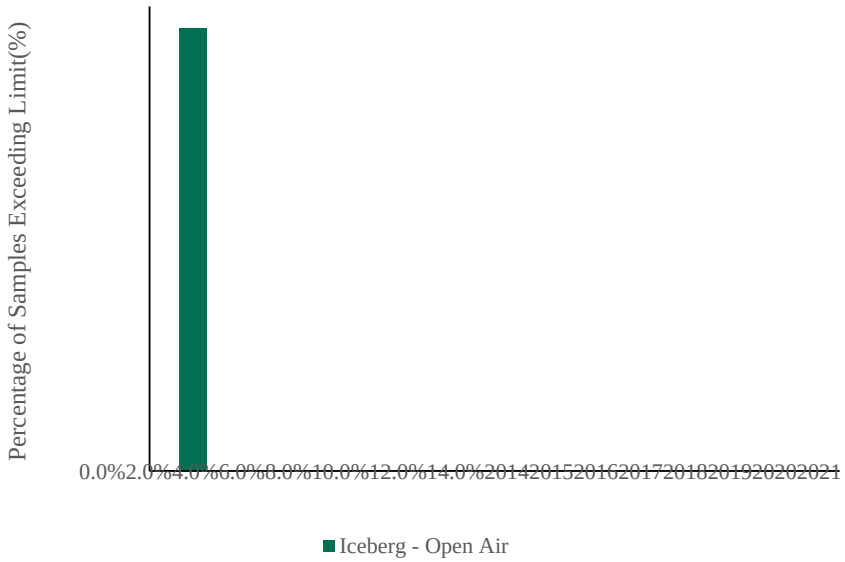

Figure 12. Proportion of open air iceberg lettuce exceeding regulation thresholds since 2014.

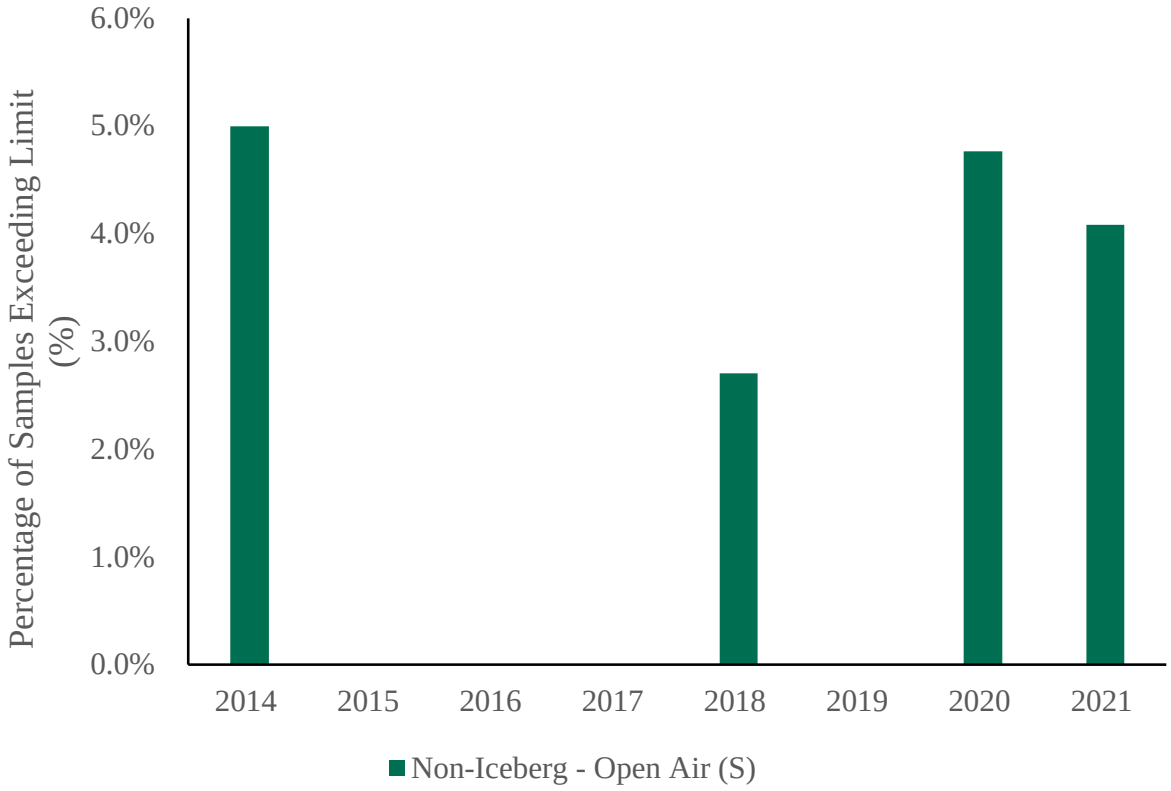

Figure 13. Proportion of open air non-iceberg lettuce exceeding regulation thresholds since 2014.

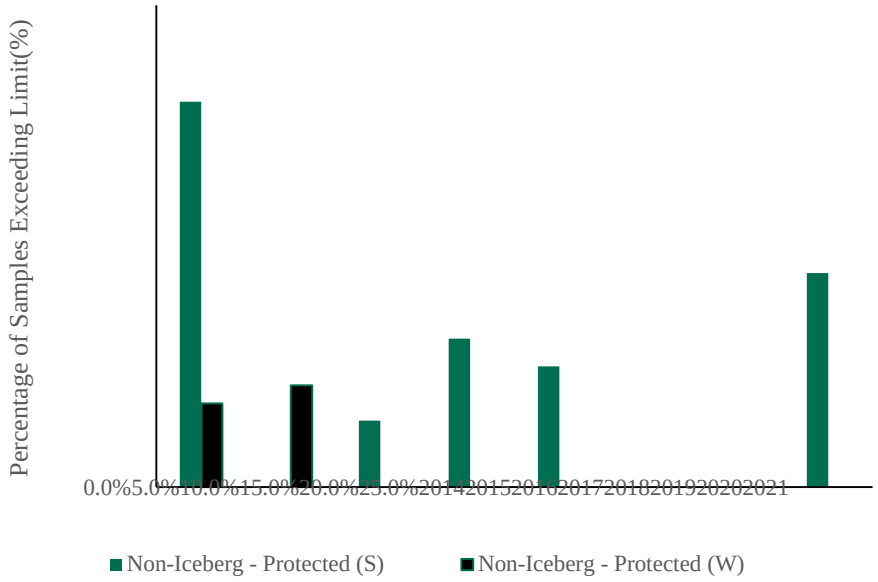

Figure 14. Proportion of protected non-iceberg lettuce exceeding regulation thresholds since 2014.

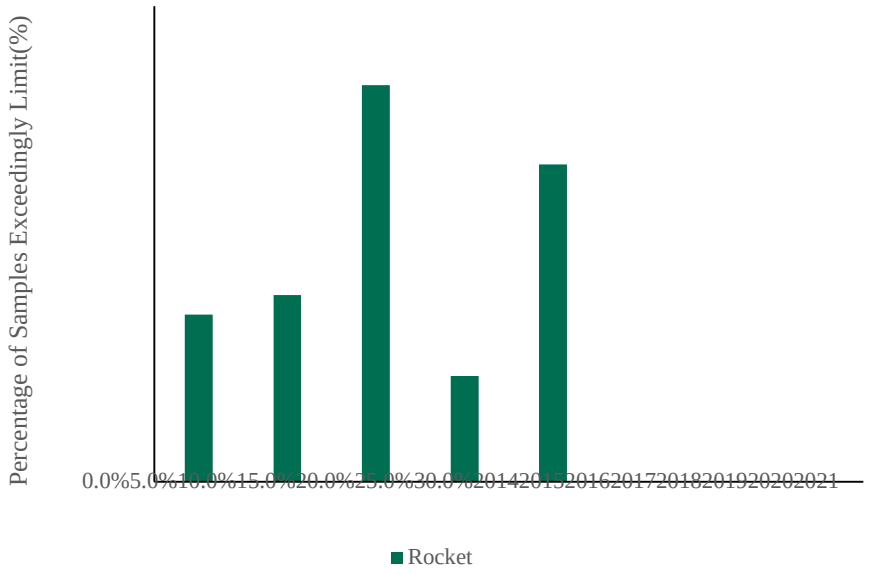

Figure 15. Proportion of rocket exceeding regulation thresholds since 2014.

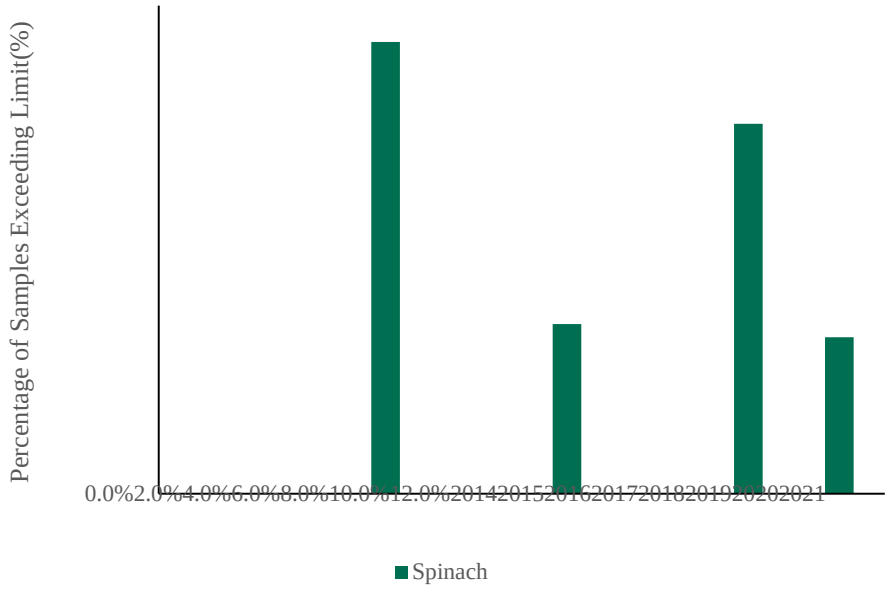

Figure 16. Proportion of spinach exceeding regulation thresholds since 2014.