

Feeding recovery was not observed in *Citrus limon* treatments and was therefore excluded from statistical analysis. This exclusion limits comparability across all treatments and should be considered when interpreting the results.

Overall, recovery performance was most favourable in *Citrus sinensis* and least favourable in *Citrus limon*, indicating variation in post exposure physiological stress responses.

3.9 Comparative cost analysis of anesthetic agents

A comparative cost assessment of citrus extracts and conventional anesthetic agents is presented (Table 9). Cost estimates were derived from prevailing local market prices in southern Nigeria.

This analysis is descriptive and was not subjected to statistical testing. The values are intended to provide indicative comparisons rather than definitive economic conclusions, as costs may vary depending on location and market conditions.

Table 9 Comparative cost analysis of citrus leaf extracts and synthetic anesthetics

Anesthetic source	Preparation/market cost (₦ per literEffective concentration (mg L ⁻¹)	Estimated cost per 1 000 L tank (₦)
Sweet orange	1 834 3 000	5 501
Sour orange	1 757 3 000	5 272
Lemon	1 910 3 000	5 730
Clove oil	27 504 40	27 504
MS 222	38 200 100	38 200

Estimated preparation or market costs of citrus leaf extracts and commonly used synthetic anesthetics, including clove oil and MS-222, expressed per litre equivalent and extrapolated to the cost of treating a 1,000 L tank at effective working concentrations. The table highlights relative economic efficiency of plant-based anesthetics under practical aquaculture conditions.

It should be noted that cost estimates presented in this study are context-specific and reflect prevailing local market conditions in southern Nigeria at the time of the experiment. As such, the values are intended to support comparative evaluation among anesthetic options rather than to provide absolute or universally applicable economic benchmarks.

Table 10 Post-exposure recovery behavior

Treatment	Species	Swimming Recovery (min)	Feeding Recovery (min)
Sweet Orange	<i>O. niloticus</i>	5.2 ± 0.27 ^a	18.0 ± 0.82 ^a
Sweet Orange	<i>C. gariepinus</i>	6.1 ± 0.33 ^a	20.3 ± 0.91 ^a
Sour Orange	<i>O. niloticus</i>	10.5 ± 0.41 ^b	35.2 ± 1.18 ^b
Sour Orange	<i>C. gariepinus</i>	11.8 ± 0.46 ^b	37.0 ± 1.24 ^b
Lemon	<i>O. niloticus</i>	14.0 ± 0.58 ^c	Not recovered
Lemon	<i>C. gariepinus</i>	15.2 ± 0.63 ^c	Not recovered

Values are mean ± SE (n = 3). Different superscripts indicate significant differences at p < 0.05 (ANOVA, Tukey's HSD). Feeding recovery was not observed in lemon-treated groups and was excluded from statistical comparison. Welfare recovery was fastest in *C. sinensis* and poorest in *C. limon*, indicating differential physiological stress responses.

The results indicate that aqueous citrus leaf extracts exhibit differing anaesthetic profiles in freshwater fish species. *Citrus sinensis* appears to offer a more favourable balance between efficacy and safety, while *Citrus aurantium* and *Citrus limon* demonstrate greater potency but reduced safety margins.

It is important to emphasise that these findings are based on controlled experimental conditions with limited replication. Therefore, the observed patterns should be interpreted as preliminary evidence, and further studies