presence of volatile compounds and alkaloids therefore explains the strong anaesthetic action and limited tolerance reflected in the comparative performance presented in Table 6.

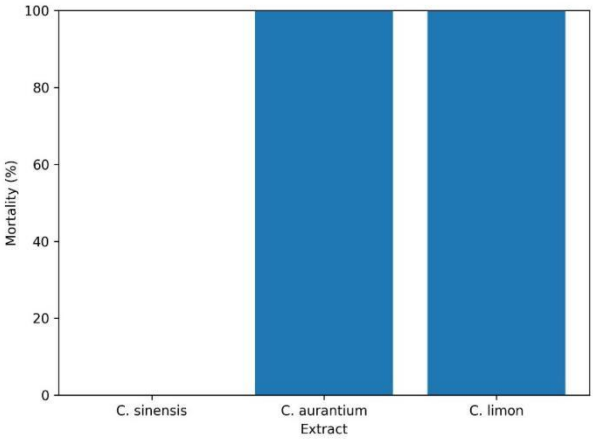

Figure 2 Mortality rates of fish at the highest concentration of citrus leaf extracts

Overall, the results support the interpretation that the anaesthetic properties of citrus leaf extracts are governed by a balance between compounds that induce neural depression and those that preserve physiological stability. Figure 1 clarifies behavioural recovery quality across treatments, complementing quantitative recovery durations in Table 5 and Figure 3 (Mphande et al., 2023).

4.2 Species specific responses to anaesthetic exposure

The differences observed between *Clarias gariepinus* and *Oreochromis niloticus* in Table 2, Table 3, and Table 10 indicate that species specific physiological characteristics play a decisive role in shaping anaesthetic response. African catfish exhibited greater tolerance and more stable recovery patterns, which is evident in the absence of mortality under certain treatments in Table 4 and the relatively favourable recovery outcomes shown in Table 10.

This resilience can be attributed to the adaptive physiology of *Clarias gariepinus*, which includes accessory respiratory structures that allow the utilisation of atmospheric oxygen. This adaptation reduces reliance on gill based respiration and enhances tolerance to compounds that interfere with oxygen exchange (Klimuk et al., 2024). In addition, African catfish has been shown to maintain physiological stability under environmental and chemical stress conditions that are detrimental to other species (Dawood et al., 2022).

In contrast, *Oreochromis niloticus* demonstrated greater sensitivity to the extracts, particularly those containing essential oils, as reflected in behavioural responses in Table 3 and delayed recovery patterns in Table 10. This increased sensitivity is consistent with the species' reliance on gill mediated respiration, which makes it more vulnerable to compounds that disrupt oxygen uptake (Bonham, 2022; Webster and Lim, 2024).

The progression of behavioural changes observed in Table 2 and Table 3, including loss of equilibrium and reduced opercular movement, follows the recognised stages of fish anaesthesia (Vergneau Grosset and Benedetti, 2022). However, the differences in response intensity and recovery between species align with previous studies showing that metabolic rate, respiratory efficiency, and stress tolerance influence anaesthetic outcomes (Ak et al., 2022; Hoseini et al., 2022). These findings emphasise the necessity of species specific optimisation in the application of plant derived anaesthetics.

4.3 Anaesthetic efficacy, recovery dynamics, and safety considerations

The inverse relationship between induction time and recovery time illustrated in Figure 3 reflects a fundamental principle of anaesthetic pharmacodynamics in fish. Increased extract concentration resulted in faster induction but prolonged recovery, indicating greater uptake and accumulation of active compounds through the gills. This