3.1. Properties of TiO$_2$ nanoparticles

![XPS spectra for Ti 2p](image1)

**Fig. 1** XPS spectra for Ti 2p of a. TiO$_2$ purchased from Aladdin; b. TiO$_2$ synthesized from TBOT; and c. TiO$_2$ in the in-situ synthesized TFN membranes

The XPS image in Fig. 1 shows the Ti 2p spectra of TiO$_2$ NPs (Aladdin), TiO$_2$ NPs generated by TBOT hydrolysis, and TiO$_2$ in the in-situ TFN membranes. Generally, the binding energy of titanium dioxide is 458.7 eV at Ti 2p$^{3/2}$ and 464.6 eV at Ti 2p$^{1/2}$, which were similar to the values observed for each type of TiO$_2$ particle. As shown in Fig. 2, the peak values of the TiO$_2$ synthesized from TBOT and that in the in-situ synthesized TFN membranes were very close that of TiO$_2$ purchased from a commercial source, indicating that TiO$_2$ particles were produced from TBOT during membrane fabrication. The fixation of in-situ synthesized TiO$_2$ in the polyamide layer was very stable because of Ti$^{4+}$ coordination and H-bonding between carboxyl groups and TiO$_2$ nanoparticles, which enhanced water flux while maintaining reasonable rejection performance.

![XRD spectra](image2)

**Fig. 2** XRD spectra of a. TiO$_2$ nanoparticles synthesized from TBOT and b. TiO$_2$ nanoparticles purchased from Aladdin

The crystal type of the TiO$_2$ nanoparticles was further confirmed by XRD analysis. TiO$_2$ synthesized in-situ from TBOT did not show an obvious characteristic peak, indicating that the TiO$_2$ in the TFN membranes was in an amorphous state. Crystal TiO$_2$ can be formed by high-temperature calcination, but the in-situ synthesis procedure only involved heating TiO$_2$ at 80 °C, so crystallization was not achieved. To the best of our knowledge,
only a few studies have reported that the type of TiO$_2$ used in the membrane synthesis process influenced membrane performance. For example, the effects of different types of nanocrystalline materials (including rutile and anatase) on the performance and antifouling properties of ultrafiltration and nanofiltration membranes have been reported$^{1-2}$. However, the effects of amorphous TiO$_2$ on membrane performance and other membrane properties have not been studied systematically.