Low-buckled silicene is a prototypical quantum spin Hall insulator with the topological quantum phase transition controlled by an out-of-plane electric field. We show that this field-induced electronic transition can be further tuned by an in-plane biaxial strain $\varepsilon$, owing to the curvature-dependent spin-orbit coupling (SOC): There is a $Z_2 = 1$ topological insulator phase for biaxial strain $|\varepsilon|$ smaller than 0.07, and the band gap can be tuned from 0.7 meV for $\varepsilon = +0.07$ up to 3.0 meV for $\varepsilon = -0.07$. First-principles calculations also show that the critical field strength $E_c$ can be tuned by more than 113%, with the absolute values nearly 10 times stronger than the theoretical predictions based on a tight-binding model. The buckling structure of the honeycomb lattice thus enhances the tunability of both the quantum phase transition and the SOC-induced band gap, which are crucial for the design of topological field-effect transistors based on two-dimensional materials.